

**"Study on Seed Germination, Seedling
Growth and Biomass Production in
Jatropha curcas L."**

THESIS

**Submitted for the award of degree of
Doctor of Philosophy
in
AGROFORESTRY**



**Submitted to
Department of Agroforestry
Institute of Agricultural Sciences
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Dedicated
To
My beloved
Parents

राष्ट्रीय कृषिवानिकी अनुसंधान केन्द्र

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CERTIFICATE

It is certified that the thesis entitled "**Study on seed germination, seedling growth and biomass production in *Jatropha curcas* L.**" is a record of bonafide research work carried out by **Mrs. Neelu Singh** for submission to the Department of **Agroforestry**, Institute of Agricultural Sciences, Bundelkhand University, Jhansi for partial fulfillment for the award of the degree of **Doctor of Philosophy** in **Agroforestry**.

The work has been carried out at National Research Centre for Agroforestry, Jhansi under supervision of Dr. R. V. Kumar, Senior Scientist (Plant Breeding).

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This is to certify that the Thesis entitled “**Study on seed germination, seedling growth and biomass production in *Jatropha curcas* L.**” submitted by **Mrs. Neelu Singh** to the Department of Agroforestry, Institute of Agricultural Sciences, Bundelkhand University, Jhansi for partial fulfillment for the award of the degree of **Doctor of Philosophy in Agroforestry** is a record of bonafide research work carried out by her under my supervision and guidance. **Mrs. Neelu Singh** has worked on this problem for a period of more than 200 days and the thesis in my opinion is worthy for consideration of the award of the degree of Doctor of Philosophy in Agroforestry in accordance with the regulation of this Centre and Bundelkhand University, Jhansi. The results embodied in this thesis have not been submitted to any other university or institution for the award of any degree or diploma.

Plumai
16.01.09

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DECLARATION

I hereby declare that the present work entitled "**Study on seed germination, seedling growth and biomass production in *Jatropha curcas* L.**", being submitted for partial fulfillment for award of the degree of **Doctor of Philosophy in Agroforestry**, Bundelkhand University, Jhansi is an original piece of work done by me under the supervision and guidance of **Dr. R.V. Kumar, Senior Scientist (Plant Breeding), NRCAF, Jhansi**. To the best of my knowledge, any part or whole of this research work has not been submitted for a degree or any other qualification of any university or examining body in India / elsewhere.

Date: 16/01/09
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I affirm all the responsibility for its shortcomings and limitations.

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Place: Jhansi

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Introduction

INTRODUCTION

The economic development of any developing country depends on its self-reliance in energy needs. Economic and industrial development made by man had been closely associated with the substitution of one form of energy with another. The current requirement of the country necessitates search for alternative sources for energy, which are renewable, safe and non-polluting. In recent years, research has been directed to explore 'Biofuels' that is plant based fuel sources, as a supplement or substitute of fossil fuels. Biofuels are gaining importance in light of increasing demand, especially fossil fuels which are now renewable. Biofuels are renewable, biodegradable, non-hazardous and safer for air, water and soil and its use reduces the emission of green house gases.

Biodiesel can be used in any diesel engine with few or no modifications. It can be used in its pure form or blended with petro-diesel. The main effect is super-lubrication, which has the benefit of acting like a solvent to clean the engine. As compared to petrodiesel, biodiesel significantly reduces the lifecycle of carbon dioxide emissions. On an average, it reduces emission of particulate matter by 40-65 per cent, unburned hydrocarbons by 68 per cent, carbon monoxide by 44-50 per cent, sulphates by 100 per cent, and polycyclic aromatic hydrocarbons by 80 per cent and the carcinogenic-nitrated polycyclic aromatic hydrocarbons by 90 per cent (Brook and Bhagat, 2004). Among the many species, which can yield oil as a source of energy in the form of bio-diesel, *Jatropha curcas* has been found most suitable due to its various favorable attributes like hardy nature, short gestation period, high oil recovery and quality of oil, etc. The seed yields approach 6-8 tonnes/ha that is equivalent to 2,100-2800 litres fuel oil/ha (Gaydou *et al.*, 1982). The seed of *Jatropha* contains about 38-40 per cent non-edible oil regarded as a potential fuel substitute of diesel (Keith, 2000; Joshi, 2005). Curcas oil can be used for diesel engines for farm equipments as it improves the engine performance and fuel consumption. When compared with diesel oil for exhaust gas like CO and SO₂, curcas oil values were

lower than the accepted values as per the standard specification of the Environment Board, and thus appears to be less polluting.

The genus *Jatropha*, family Euphorbiaceae is a morphologically diverse genus comprising 160-175 species of shrubs, rhizomatous shrubs, herbs and small trees. In India 14 species have been recorded so far and they show wide variation in vegetative, floral characters and oil content. Out of these, important ones are *Jatropha curcas* Linn, *J. gossypifolia* Linn, *J. glandulifera* Roxb, *J. multifida* Linn, *J. nana* Dalz. and *J. podagrica* (Anonymous, 1959). *Jatropha curcas* is a wild growing hardy plant well adapted to arid and semi arid conditions. Commonly known as Physic nut, Ratanjyot, Jamalgota, Jangli arandi, or Kala aranda, it is a multipurpose, deciduous, large, 3-4 m high shrub. It is a native of Mexico and tropical South America and is widely distributed in wild and semi cultivated strands in the world including Brazil, Fiji, Jamaica, Rico and Salvador (Holm *et al.*, 1979). It grows in a number of climatic zones in tropical and sub-tropical regions of the world and can be grown in areas of low rainfall and problematical sites. *Jatropha* is easy to establish, grows relatively quickly and is hardy. Being drought tolerant, it can be used to reclaim eroded areas, be grown as a boundary fence or live hedge in the arid/semi-arid areas. It has low fertility and moisture demand and can come up on stony, gravelly or shallow and even calcareous soil. In India, Portuguese navigators introduced it in the 16th century as an oil yielding plant. Now it is occurring almost through out India and in Andaman Islands in semi wild conditions. It is reported to be cultivated in Central and Western India in states like Rajasthan, Madhya Pradesh, Maharashtra and Gujarat as well as in southern states like Andhra Pradesh and Tamil Nadu. *Jatropha* is derived from two greek words- *jatro* means Doctor and *trophe* means Nutrition. *Jatropha* has long productive life of around 40 years and yields the biodiesel source, the seed from third year onwards. It is generally grown as live fence in almost all parts of India. Seed cake being rich in nitrogen is also an excellent source of plant nutrients. The uses of *Jatropha curcas* are varied and have ranged from serving as medicine to providing a slow drying non-edible oil (known as curcas

oil) used as an industrial raw material in the manufacture of candles, soap etc. The root bark is used externally for the rheumatism. The leaves warmed and rubbed with castor oil are used as a supportive. The green tender leaves are used for tooth brushing in villages. The sap of the plant is used to cure toothache and to stop bleeding. The oil is also used as a purgative and the seed oil is topically applied in coetaneous diseases in Guinea, herpes and pruritus. Nearly half the world's poorest people live on marginal lands with the number expected to increase from 500 million to 800 million by 2020. These areas are by definition isolated and fragile, with soils susceptible to erosion and subjected to environmental stresses of deforestation, prolonged droughts, and decreasing soil and ground water. *Jatropha* is not browsed, for its leaves and stems are toxic to animals, but after treatment, the seeds or seed cake could be used as an animal feed. Being rich in nitrogen, the seed cake is an excellent source of plant nutrients. Various parts of the plant are of medicinal value, its bark contains tannin, the flowers attract bees and thus the plant has honey production potential. Like all trees, *Jatropha* removes carbon from the atmosphere, stores it in the woody tissues and assists in the build up of soil carbon.

The wood and fruit of *Jatropha* can be used for numerous purposes including fuel. The seeds of *Jatropha* contain (50% by weight) viscous oil, which can be used for manufacture of candles and soap, in the cosmetics industry, for cooking and lighting by itself or as a diesel/paraffin substitute or extender. This latter use has important implications for meeting the demand for rural energy services and also exploring practical substitutes for fossil fuels to counter greenhouse gas accumulation in the atmosphere. It can be grown over a wide range of arid or semi-arid climatic conditions, well adapted to harsh conditions of soil and climate (Tewari *et al.*, 1994). It is recommended as drought resistant plant and suitable for erosion control. Like other tree species, *Jatropha curcas* also helps in carbon sequestration.

India's economy is based on agriculture and there is large scope for production of bio-diesel from *Jatropha* as block plantation on degraded and wastelands or plantations in different agro-forestry systems in the country and providing

employment potential to tribal and rural population by seed collection. India is facing a severe crisis with increasing conflict arising from the need to produce more timber, fuel wood, fodder and other non-wood forest products for both domestic and industrial uses and at the same time need to maintain an adequate degree of environmental protection. Forest areas continue to decline as a result of deforestation and conversion of forests for non-forestry purposes. The per capita forest area in India is less than 0.08 ha which is very low when compared with the world average of 0.80 ha. The productivity of our forests estimated from the average annual production of wood per hectare works out to be about 0.7 cu. m., which is very low as compared to the world average of 2.1 cu. m. The country has a large population of rural and tribal people who still depend heavily on forests for their basic needs *i.e.*, fuel wood for energy, small timber, bark, gum, medicines etc., for domestic use and tree fodder to feed their cattle. Though the rural people use the non-conventional sources of energy like agricultural wastes and animal dung, firewood forms about 68.5% of the energy source. There is a vast gap between the demand and production of fuel wood in the country. The annual requirement, being of the order of 235 million cu. m., when compared to the annual recorded production of about 40 million cu. m. it leaves a gap of about 295 million cu.m. The annual requirement of timber including pulp and paper, matchwood, sports goods, railway sleepers, construction work etc., works out to be 27.5 million cu. m. The extraction of timber as per silvicultural availability is approximately 12 million cu. m. leaving a gap of about 15.5 million cu. m.

In some other countries like the Italy, Malaysia, Austria and Nicaragua, *Jatropha* oil is already being used as a substitute for diesel. These characters along with its versatility make it of vital important to developing countries. In India, *Jatropha* is found in almost all states and generally grown as a live fence for protection of agricultural fields. India is particularly well suited for a green alternative fuel because of its estimated 50-130 m ha of wastelands *i.e.* saline lands, degraded forests and other land unavailable for agriculture, shifting sand dunes and fastest growing population in the world. The climatic conditions make *Jatropha*

especially attractive because it is a drought resistant species, adapted to a wide range of climates and soils, arid and semi-arid conditions and has low fertility and moisture requirement. It is capable of stabilizing sand dunes by acting as a windbreak. It prefers warmer regions of tropics and subtropics with annual rainfall 300-1000mm. The promotion of *Jatropha* plantation can generate tremendous job opportunities among the rural masses. Simultaneous production of indigenous bio-diesel from its oil resists the outflow of foreign exchange caused by the import of crude petroleum.

These characteristics along with its versatility make it of vital importance to developing countries subjected to decreasing tree cover and soil fertility because of increasing population and development pressures. A good reason for developing *J. curcas* as a new energy crop is that it does not compete with conventional food crops for land, water and manpower resources and also its ability to make a significant contribution to the nation's growing needs of energy through large scale cultivation with ease. The unique adaptation of *J. curcas* and its productivity even on arid lands makes it the most important plant economically as it produces oil seeds having a very high energy value and multiple benefits.

Despite these characteristics, the full potential of *Jatropha* is far from being realized. It is therefore timely to examine the potential role that *Jatropha* can play in meeting some of the needs for energy services for rural communities and also creating avenues for greater employment.

First step in any species improvement programme begins with the study on variations present in important economic characters of that particular species of interest. When species variation range is known according to its geographical distribution, the seed source/ provenance selection of that species can easily be done for the success of any plantation programme. This will definitely lead to enhancement of productivity. Advance tree improvement programmes are also based on the natural variations present in improvement trials of the species over a wide range of geographical areas, resulting from genotype-environment interactions. If a particular character is heritable, it will certainly attract the breeders. Besides *J. curcas*, there are

over 160 other types and varieties of genus *Jatropha* which can possibly be hybridized with *J. curcas* to produce high yielding hardy plants than the parent plants, and which could possibly be made to bloom faster and earlier. Apart from this there are a number of indications about the existence of many sub-species of *J. curcas*. Because of its vast natural distribution in different parts of India it would be expected to have considerable genetic variations. In spite of many uses, genetic efforts are lacking. Variability studies, which provide the basic information, required for genetic improvement of species under any agro climatic situations are of paramount importance. If this information is used selectively for cultivation, there exist a number of possibilities to get higher yields in the future. The published results on improvement of *J. curcas* are very limited. Till date no regular seed collection from the existing semi wild or cultivated bushes has been done for any end use in our country. The seed oil productivity is very low at present, since it has never been improved as oil crop and the basic knowledge for domestication is quite limited. Systematic efforts have not yet been made for better cultivation and for increase in production by using present day knowledge of plant breeding and increased agronomic experiences.

There is a considerable scope for the improvement of our indigenous and economically important species that are relevant to the rural communities as well. *J. curcas* being a naturalized species, its ability to grow in varied eco-climatic zones and its wide range of distribution embraces a considerable scope of variation which suggests a high potential of this genus in India. There could be a lot of-variations existing in seed quality, growth, yield, oil content and biomass production from one origin to another as regards to morphological variation and physiological difference.

However, there is no information available about the performance and suitability of various provenances, not only for optimizing the biomass and productivity for reforestation work but also for the production of *Jatropha* oil which could serve as an alternative means of fuel in future.

In the exploitation and improvement of any species, genetic gain through eugenic silviculture plays an important role which can be capitalized by simple selections in trees on the vast reservoir of variation that a species is embodied over its distribution range for the development of fast growing clones/strains.

Considering vast semi-wild distribution of *Jatropha*, it is expected to have considerable genetic variation. Sufficient information on such aspect is lacking in this species in spite of its many uses. Environmental factors in combination with genetic and physiological factors play an important role in determination of plant potential for seed quality. These characters appear to be under strong genetic control. The cultivation of *Jatropha* has begun world over for biodiesel production but unfortunately, there is a lack of appropriate technology and availability of quality planting stock material. Seed management is also an inevitable practice for successful crop/ tree production. Sowing is a pain stick nursery operation. Its objective is to obtain, from the best seed available, the maximum number of healthy and sturdy seedlings for transplanting and to find out the accessions that have good germination capability. The seed sowing can be done either in the poly-bags or in the nursery beds.

The *Jatropha* seeds show epigeous germination in which, the hypocotyls elongates and raises the cotyledons above the ground. Temperature affects both germination percentage and germination rate. Germination rate is invariably low at low temperature, but increases gradually as the temperature rises. Light has been recognized since in the mid-ninetieth century as a germination-controlling factor. Recent research demonstrates that light acts in both dormancy induction and release and is a mechanism that adapts plants to specific niches in the environment; often interacting with temperature, light can involve both quality and photoperiod.

If the seed lots posses high genetic purity, high germination percentage and a minimum of inert, weed and other crop seeds and are free from diseases, it is said to have high quality. Some other characteristics such as seed size, weight and gravity has been found to have positive correlation with seed germination and vigour in many crops. The seed lots having smaller seeds, lower specific gravity of hundred seed

weight may perform poorly when compared with lots having higher specific gravity and hundred seed weight. High germination percentage and vigour results into raising of an excellent crop having adequate plant population and uniform growth. Both of these have profound effect upon the ultimate yield, and also determine the planting value of seeds.

Seed germination is an important determinant for the populations of a species. Germination energy and germination capacity are criteria for early selection of fast growing provenances, and further the selection of provenances with great dormancy may play an important role in afforestation of wastelands. The germination potential is an important indices for selection, however, germination pattern reflected through germination value is considered more relevant to realize early completeness in germination and to produce uniform stock. To produce good quality and quantity of seed for bio-fuel, quality planting material is required which can be generated by enhancing the quality of seed. Seeds of *Jatropha curcas* have low viability percentage and loose viability after 6 months. Seeds of the species showed orthodox storage behaviour (Khare *et al.*, 1993).

Seed quality has great impact on quality of planting stock. Careful attention to seed collection is critical to obtain good quality forest tree seed. Successful collection depends on understanding seed maturation and dispersal characteristics of each species. Immature seed can bring about various problems including slow or no germination.

Low vigour seed results in smaller seedlings having greater susceptibility to insect, pest and diseases and also reduced storability of seeds. Irregular and often infrequent seed production by many of the major tree species necessitates seed storage, sometimes for several years to maintain supplies through years of poor seed production. Seed storage is one area of forest tree seed technology for which sufficient information is not available for most of the oil bearing tree species.

Successful seed storage required knowledge of the seed characteristics of different trees as well as factors influencing storage capacity, such as seed quality

before storage, seed moisture content and storage temperature and methods. Seed moisture content is controlled by storing properly dried seeds in tightly closed containers or by regulating humidity in the storage area. The most frequently used storage containers are plastic, polythene bags and storage bins. The seeds unlike agriculture seed are in many cases characteristics by deep dormancy. When viable seed *i.e.* seeds with capacity to germinate and grow is unable to germinate even in favourable environmental condition of adequate water supply, aeration and appropriate temperature for germination, they are considered to be dormant.

Viability testing of seed is an important task to improve plantation. Tetrazolium testing has been an important and useful tool in determination of viability in a number of species, it was 1st introduced by Lakon. The test can evaluate the viability of seeds rapidly, also when in a state of dormancy. The method has gained popularity mainly because of its simplicity, easy and rapidity of application (Gera *et al.*, 2003).

Germination potential is most important measurement in seed testing to determine the viability of seeds as it varies on account of habit, species and source. One of the factors influencing seed longevity is seed moisture contents, as the moisture of seed decreases with increasing storage, with increasing storage time, the viability of seed is also affected. The moisture content of seeds is one of the important factors influencing the period. High moisture content at harvest can increase the liability of the seed to threshing damage and later, in storage, viability decreases more rapidly at high moisture content because of mould growth, heating damage, ageing and increased insect damage. Therefore, it is of great value to know the moisture content of the seed directly after harvest and when necessary, also after artificial drying.

The germination of seeds is strongly influenced by variation in temperature, water stress and light requirement and these factors often show significant interactions in this effect on germination (Bokhari *et al.*, 1975; Rao *et al.*, 1986).

Generally in seed germination of forest trees, light is an important factor, with some exceptions, but in nearly all cases germination is improved and hastened by it.

The study of proper sowing depth is essential for the successful seedling emergence and subsequent growth because of difference in the micro-environments at various soil depths. The time of sowing and different shade level also affect the seed germination as well as seedling growth.

Ecological requirements for plantations

Jatropha curcas can be grown on a wide range of soil types and agro-climatic conditions. Its introduction in India and subsequent escape testifies for the wide range of soils-from coastal zones to gravelly Himalayas-with rainfall ranging from 300mm to 1000mm. This is a testimony to the wide adaptability of this species. However, it grows well in areas with a rainfall above 400 mm, and at lower elevations (0-55 msl (mean sea level)). The plant species is not very sensitive to day length, and can tolerate light frost. It has been proven that it is a light demander, and seed yield reduces drastically under shade and in cold regions.

Nursery

Nurseries are very important in social forestry because by and large, container plants are required to be used for very valid reasons. First, it is necessary to ensure a much quicker rate of growth than in conventional plantations because of browsing damage and the need for quicker returns.

In the recent years, importance of nursery grown seedling has grown immensely because of heavy requirements of seedlings both for supply to the public for planting under social forestry programmes and for massive afforestation programmes taken up by the Government. Whereas for a social forestry project, it is the choice of species and the location of nursery that matters much, for artificial plantations, it is capacity of the nursery that matters most is delivery of seedlings. The cost of various raising plantations rises high if the production of seedlings is delayed;

seedlings are under sized, mal nourished or short of numbers. A well planned nursery with time - framed operations, growing genetically improved plants with abundant supply for field planting is therefore, always essential. Rapid early growth of trees in nurseries enables early feed establishment of seedling and also improves the efficiency of nursery operations. For the supply of quality planting material for agroforestry programmes, nurseries are essential.

Jatropha in agroforestry-forestry model

Agro forestry is a land management system optimizing land productivity by harnessing positive interactions between tree crop livestock system on a land area. It is a holistic concept that involves various organisms sharing a habitat, and its abiotic and biotic components. Though forestry activities are mainly with the government, rural people have been practicing tree plantation in their farms and homestead in order to meet the household requirements for fuel, fodder, poles, timber, fruit, and non timber forest produce. The objective of agroforestry is to take advantage of complimentary relationships between trees, crops and live stock in a way that productivity, stability and sustainability of the total system exceed most single cases. Currently, this area under agro forestry (including farm forestry) in India is over six million hectares. Nearly ten million hectares is covered with rubber, cashew, coconut, mango and other species.

If 900 *Jatropha* plants (including boundary) are planted in one hectare area in wheat-bajra crop rotation for eight years, it can generate 225000 rupees for farmers (Compendium, 2006). Thus, it is a potential technology for commercial farming, improving degraded and polluted sites, an opportunity for stabilizing fragile ecosystem and also a farming system for arid and semi-arid zones.

Botanical description

Jatropha is a small tree or large shrub, up to 8 m tall and with diameter up to 20 cm. Trunk is straight, branching low above the ground; bark is thin and yellowish.

Leaves are 6 x 15 cm and lobed. Flowers are small and greenish, unisexual with male and female flowers at the same tree. Fruits are grey-brown capsule, up to 4 cm long; it is normally divided into 3 cells, each containing one seed. Seeds are black, about two cm long and one cm thick. There are 1200-1600 seeds per kg.

Flowering

The *Jatropha* trees are deciduous, shedding the leaves in the dry season. Flowering occurs during the wet season and two flowering peaks are often seen. In permanently humid regions, flowering occurs throughout the year.

Availability

Jatropha is very prominent, widely acclaimed with wide variety of uses. It has a high potential for quick greening and eco-rehabilitation of wastelands as well as for bio-aesthetic reasons. It is found in India in a semi wild condition in the vicinity of villages. It is commonly grown as live hedges around agricultural fields as seeds or branch cuttings can easily propagate it. Being a naturalized species with a wide range of distribution and its ability to grow under varied agro climatic conditions, *J. curcas* embraces a considerable scope of variation, which suggests a high potential of this genus in India. There is a huge scope for the improvement of this economically important species, which is relevant to rural communities.

Storage and viability

The seeds are orthodox and should be dried to low moisture content (5-7%) and stored in air-tight containers. At room temperature the seeds can retain high viability for at least one year. However, because of the high oil content the seeds cannot be expected to store for as long as most orthodox species.

sowing and germination

Germination of *Jatropha* seeds is fast under good conditions it is complete in 10 days. Germination is epigeal (cotyledons emerge above ground). Soon after the first leaves have formed, the cotyledons wither and fall off. In the nursery, seeds can be sown in germination beds or in containers. Although the seedlings grow very fast they should stay in the nursery for 3 months until they are 30-40 cm tall. By then the plants have developed their repellent smell and will not be browsed by animals.

Physic nut can be established from nursery seedlings, bare root or containerized, by direct sowing, transplanting of seedlings or planting of cuttings. The choice of propagation method depends on use. Plants propagated by seeds are generally preferred for the establishment of long-lived plantations for oil production.

Direct sowing should only be used in areas with high rainfall and the seeds must be sown after the beginning of the rainy season when sufficient rainfall is certain. For quick establishment of hedges and plantations for erosion control, directly planted cuttings are best suited. Cuttings of 30 cm length have been found to have the highest survival rate. Plants propagated by cuttings will normally produce seed within one year of planting and growth is rapid.

BROAD OUTLINE OF THE WORK

The review of literature on seed germination and seedling growth and biomass production of *Jatropha curcas* summarized above clearly pinpoints that the current status of information on the subject is very scanty or negligible in terms of scientific information on seed storage, germination, effect of pH, light, temperature, water stress, time and depth of sowing, effect of container and seed mixtures on seedling growth and biomass production of the species. Hence, the proposed study is an attempt to provide a complete package of information in all these aspects which will help in producing quality planting material at nursery level.

OBJECTIVES

Keeping in mind the information needed in this species, the present research work is being proposed with the following objectives for *Jatropha curcas*:

1. To study the seed longevity and germination under different storage conditions.
2. To standardize time and depth of sowing for optimum seed germination and seedling growth.
3. To study the effect of light, temperature, shade, pH and water stress on seed germination.
4. To compare the growth performance of poly bag and seedbed grown seedlings under different filling mixture.

Review of

Literature

REVIW OF LITERATURE

Production of quality seedlings is an important aspect of successful planting of any species. A lot of information is available on seed germination as well as seedling growth and biomass production of different plant species under different sets of growing conditions for producing large quantity quality planting material. But after growing through the available literature, it is clearly visible that very little work has been done in *Jatropha curcas* on the aspects of study on seed germination and growth and biomass production of seedlings. Until and unless a detailed study on this aspect is conducted, it will be very difficult to come out with a package of information for getting maximum germination and good and vigorous seedlings at nursery level. As this is much needed species of today for producing bio-diesel and saving a lot of money required for importing diesel, a careful attention is needed. Here it has been tried to pinpoint the research work conducted in *Jatropha* and other species on seed germination and seedling growth and biomass production to have an insight on the present status of information available.

Some sporadic work confined to laboratory studies has been done in past on seed viability, seed germination, seedling growth and storage behaviour (Choubey *et al.*; 1997 and Tewari *et al.*, 2000). The information with regards to Botany, Taxonomy, Habitat conditions and the range of their geographical distribution has been well documented (Anonymous, 1981; Anonymous, 1988; Joshi *et al.*, 1991; Dwivedi, 1992).

There is very little report on optimization of sowing time, sowing depth, shade, light, temperature, soil mixtures and water stress on germination and seedling growth. These factors are known to play important role in seed germination and seedling growth in number of species. Information on various aspects of growth parameters for *Jatropha curcas* in particular and other shrubs and MPTs in general have been reviewed below.

2.1 Time of seed collection:

Time of seed collection is very important consideration in propagation of a plant. Collection of seeds at the proper time enhances seed germination rate and plant percent. There are reports that time of seed collection influences seed germination.

Bharadwaj and Chakrabarti (1994) reported that time of collection of fruits affects seed germination in Bahera. They reported best germination in *Terminalia bellerica*, when seeds were collected in first fortnight of January and seed sowing was done in 3rd week or last week of March. Negi and Todaria (1995) reported that time of seed collection was crucial for seed germination in Bahera. Seeds collected after 40 days of fruit shedding showed maximum germination (96.67%). Water content in seeds decreased with seeds maturity. Choubey *et al.* (1997) reported that fresh seeds of chironjee were taken for germination studies.

Ram Prakash (1998) reported that clean hard bony seeds obtained from chironjee after removal of pulp, dried in shade have about 70% germination capacity. Chaturvedi *et al.* (1999) reported that fresh Neem (*Azadirachta indica*) seeds exhibit maximum (92.8%) germination, while that sun dried even for one day quickly loose viability. On the other hand Khera *et al.* (2000) reported that seed germination of neem was significantly influenced by the time of seed collection. Seeds collected during July 7 to July 17 exhibited greater germination. Seeds stored in open conditions or in perforated cardboard box at room temperature indicated greater germination and longevity.

Chironjee fruits ripen during April-June. The seeds, lying on the ground exposed to sun, have a very low germination potential. However, fresh seeds have been found to have a fertility of <70% (Anon, 1988). If collected from the ground, only freshly fallen fruits can be taken.

2.2 Effect of seed size:

Seed size is known to influence seed vitality and seedling growth in nursery. The best seed size will lead to cent per cent germination. Sharma and Sood (1990) studied that the medium sized seeds resulted in maximum germination followed by large and the lowest germination occurred in small sized seeds, (*Leucaena leucocephala*).

Arjunan *et al.*, (1994) observed that the large sized seeds of *Pongamia pinnata* germinated better (98%) than medium sized (80%) and small sized seeds (70%) and biomass production was higher in seedlings produced from larger seeds. Ponnammal *et al.* (1993) studied that different size of Neem seed grow better in different media. The best medium was found to be mixture of sand +soil + humus (1:1:1) and the medium sized seeds (1.0 to 1.2 cm. length) exhibited 98 percentage germination.

Deleep *et al.* (1994) reported that large sized seeds of *Ceiba pentandra* weighing more than 0.055 g have to be sown in rooting medium containing soil, sand F.Y.M. in proportion of 1:1:1 to obtain better seedlings. They also reported that F.Y.M. played dominant role over seed size for production of quality seedlings. Manonmani *et al.* (1996) studied that the large seeds (100-seed weight about 135 g, compared with 111 and 84 g for medium and small seeds, respectively) of *Pongamia pinnata* were characterized by better germination and vigour index.

Murli (1997) studied that the seed size is strongly correlated with days to germination. Smaller seeds germinate faster than longer seeds. Species which flowered during the rainy season had lighter seeds than species which flowered during the dry season. It was also observed that seed size and viability of seeds were related to the season of fruiting. Species which fruits during the rainy season had heavier seeds and shorter viability than species which fruit during summer.

Negi and Todaria (1997) found that heavy and large seeds of *T. bellerica* and *A. oblongum* performed better in terms of germination, while *T. belerica* and *T. tomentosa* gave better results in terms of seedling development after 3 and 6 months respectively.

Umarani *et al.* (1997) observed that the germination (60%) and seedling growth and vigour in *C. equisetifolio* were best in the largest seeds sown on the surface, followed by the largest seed sown at 1cm depth (58% germination). Mertia and Kunhamu (2000) reported earliest germination in *Salvadora obeoides*, within 18 hours of seed placement. Cent per cent germination was recorded in large and medium sized seeds treated with cold water.

2.3 Effect of Storage:

Irregular and often infrequent seed production by many of the major tree species necessitates seed storage, sometimes for several years to maintain supplies through years of poor seed production.

Seed storage is most important consideration in seed germination of any species as seeds of various species ripe at different times of year. Very often seeds are stored for use at distant places in subsequent growing seasons. Some of the studies on type of containers, method and duration of storage on seed viability have been reviewed here.

Dabral (1976) studied that the extracted seeds germinated and give germination as high as 50% to 79% during favourable months. Periods immediately after the break of monsoon (June or July), October, February and March have been found to be the best months for germination in Chanda region. Success of germination depends upon the relative absence of the fungal attack during different months. Seeds germinate over a wide range of temperature (25⁰C to 40⁰C) but 30⁰C has been found to yield good results.

The germination completes in about 10-12 days. Mercury fungicide (dust formulation) has been used for preventing fungal attack on the extracted seeds during

storage. The extracted seeds can be stored in air-tight containers under the cover fungicide dust. Seeds stored up to 2 months have so far been tried and gave germination up to 54%. Too wet conditions cause decay of seeds. Soaking of seeds in water before sowing was found to be harmful.

Gupta and Sood (1978) studied that *Dendrocalamus strictus* seed can be stored with advantage over silica gel or anhydrous calcium chloride in desiccators or at 3°C to 5°C ambient temperature after reducing the seed moisture content to 8%. A seed lot with 67% germination capacity stored under the above conditions exhibited 51, 54 and 59% germination respectively after 34 months. Study has also indicated the presence of after-ripening in the seed, which is overcome by storage under favourable conditions.

Sharma and Jain (1981) conducted the experiments on the effect of time of collection and storage of Sal (*Shorea robusta* Gaertn.) seed kernels for a period ranging from 15 to 150 days stored under various conditions. The yield and quality of the oil extracted from stored kernels after stipulated periods have been determined for the acid, ester and iodine values. The effect of storage on the quality of the Sal seeds fat stored for one year has also been examined.

Athaya (1985) reported that seeds of *Acacia catechu*, *A. leucophloea*, *Albizia procera*, *Terminalia arjuna* and *T. belerica* had a higher germination percent when kept in the middle layer of the container (open or closed glass-stoppered bottles) than kept in the top or bottom layers. Ezumath (1986) reported that Neem seeds dried to 16 to 11% moisture content under air drying and sun drying recorded the same germination of 83% as that of fresh seeds at 38% moisture contents.

Maithani *et al* (1987) studied that extracted seeds exhibited better germination as compared to the fruits. There is no statistically significant difference in germination capacity of fresh black and green seeds, but green seeds lost germination capacity within 2 months in open storage at room temperature while black seeds exhibited negligible deterioration even after 6 months.

2.4 Effect of container:

Raising seedling of tree species in nurseries is a common phenomenon in present day plantation programme of agroforestry and forestry, all over the world. Most of the nurseries use polythene bags and other containers for raising nurseries.

Arnott (1981) studied a few comparative trials on field performance between containerized seedlings of bare root nursery stock. Amidon *et al.* (1982) reported that under drought conditions container grown seedlings survived better than nursery stock. They further had suggested that the increased root length of container grown seedlings survive better under drought condition. Several researchers found suitable container size for particular species such as 30 x 20cm for cocoa (Keshav chandran and Nair, 1985), 30 x 13cm for *Santalum album* (Karivaradharaju *et al.*, 1999), 26 x 12.6cm. for *Azadirachta indica*. (Bharti, 1999), and 25 x 15cm for *Albizia lebbeck* (Natrazan, 1999). Athaya (1985) reported that seeds of *Acacia catechu*, *A. leucophloea*, *Albizia procera*, *Terminalia arjuna*, *T. belerica* had a higher germination percent when kept in the middle layer of the container (open or closed glass-stoppered bottles) than kept in the top or bottom layers. Ezumath (1986) reported that Neem seeds dried to 16 to 11% moisture content under air drying and sun drying recorded the same germination of 83% as that of fresh seeds at 38% moisture contents.

Jesus *et al.* (1987) studied the effect of container size, type of substrate and shading on seedling growth of Leuro (*Cordia mixa*) and gencaloalves (*Astronium fraxivisfalium*). The effect of light intensity and substrate on height growth was largely influenced by container size. Both species grew better in shade and in substrate with more organic matter.

Bhagat *et al.* (1992) reported that *Woodfordia fruticosa* seeds stored at normal room temperature showed a decline in viability from 96% to 1.25% in twelve months. Josaiah and Jones (1992) have favoured root technology for raising plants in forest nurseries. Dhiman and Sood (1994) studied different kinds of containers, i.e., earthen

pots and tubes, bamboo baskets, seed boxes, leaf cups or 'donas', tin trays, manure bricks and even cylindrical rolls of moss were used in the past.

Sah and singh (1995) studied the effect of temperature and storage on seeds of *Populus ciliata*. The results indicated that the maximum germination was obtained at 20°C. The seeds stored at +2°C retained better viability (60.5%) than the seeds stored at -10°C (30.0%) after one year of storage period.

Gurudev Chand and Bhardwaj (1996) studied the seed longevity by way of different seed storage in *Toona ciliata*. Seeds were stored in four different containers kept at three different temperatures for one year. It was found that polythene bag seeds kept at 0°C temperatures maintained 93% germination after one year in storage.

Mughal (1996) studied that the *C. torulosa* and *C. deodara* attain optimum shoot and root development when grown in open nursery in beds while as seedling grown in poly bags do not exhibit better growth in terms of height and root development. Roots of poly bags seedlings showed even deformities and confinement in immediate vicinity.

Agboola (1997) reported that seed storage of *Prosopis africana* at very low (0-22%) or very high (72.5-100%) RH adversely effected seed germination. Intermediate range of RH in storage resulted in 65-80% germination in one year and there after ward, germination was static up to 2 years.

Choubey *et al.* (1997) reported that tin containers are most suitable for storage of *Buchanania lanzan* seeds. They found that germination of seeds stored in tin container at 3, 6,9,12 and 24 months intervals were 65, 42, 25, 15 and 7%, respectively. Glass bottles proved least effective to store seeds and maintain their viability. Dod *et al.* (1997) studied that the seed of *A. indica* (9%moisture content) were stored in cloth, polylined jute, paper or polythene bags for 2 month under ambient condition. Seed stored in cloth bags maintained significantly higher viability (37.9% germination after 60 days at storage) compared with the other treatment.

Gonzalez and Fisher (1997) studied the viability of seeds of *Hyeronima alchorneoides*, *Virola koschnyi* and *Vochysia guatemalensis* collected from wild trees in Costa Rica, in relation to desiccation, seeds moisture content, and storage temperature. Seed was desiccated either in chambers with activated silica gel or using air passed through columns of activated silica gel. Two seed moisture contents were achieved: 25-30% and 6-8%. Desiccated seeds were stored at either room temperature ($25\pm 1^{\circ}\text{C}$) or in a cold room ($4\pm 1^{\circ}\text{C}$). Seeds of *V. koschnyi* and *V. guatemalensis* did not tolerate moisture loss and lost their viability completely.

Seeds of *H. alchorneoides* tolerated desiccation treatments without significant loss of viability; a combination of low temperatures ($4\pm 1^{\circ}\text{C}$) and low seed moisture content (6-8%) allowed seeds to be stored for 6 months, although mean germination was reduced by storage. Possible inhibition in the germination of *V. guatemalensis* was tested by treatment with 5 concentrations of abscisic acid: 10^{-4} , 10^{-6} , 10^{-10} , 10^{-15} and 10^{-20} m. None of the treatments stopped germination of fresh seeds. Masilamani and Vadivelu (1997) studied the seeds stored in polythene bags maintained maximum seed quality under ambient condition. Shukla *et al.* (1997) reported better germination and vigour in Aonla (*Emblica officinalis*) in one year stored seeds in comparison of fresh seed.

Purohit *et al.* (1998) reported that maximum germination was obtained in mouth tied polybags (germination 98.3%, field emergence 86.3%) and minimum in stoppered glass bottles (germination 52%, field germination 50%) after 4 months of storage. Germination and field emergence decreased gradually in all storage conditions with the passing of time.

Guofeng *et al.* (1998) reported the nursery studies in china on the production of high quality container grown seedlings of masson pine (*Pinus massoniana*) over 3 years. The use of root-unfolding-containers made possible the extension of the root system along guiding troughs instead of folds, which promoted lateral or thin root development by natural air root pruning. In a comparison of 2 types of root-unfolding-containers, the box type was better than the pipe type container, giving

12.8% and 24.6% better seedling height growth and biomass production, a lower shoot/root ratio, stronger root system, and higher seedling quality. The suitability of different growing media was assessed using a comprehensive index selection for seedling growth, root quantity, physical and chemical characteristics, seedling water relations and nutrition. The best medium was a half-light medium made of 20-40% bark powder, 20-40% saw dust, 10-20% pig manure, 30-40% nutrient (fertile) soil and 2-3% phosphorus fertilizer. Plantation survival rates were increased by the combination of a suitable root system and medium and the formation of a solid root unit. Akinola *et al.* (1999) reported that seed germination of subabool (*Leucaena leucocephala*) reduced with duration of seed storage from 270 days to 395 days.

Sharma *et al.* (1999) studied five containers viz., silica gel in a sealed plastic container, earthen pot, tin, muslin cloth bag and polyethylene bag for storing the seeds. Before storage, the seeds were dried in open shade at the State Forest Research Institute Campus, Jabalpur, for 15 days. The seeds were stored for up to 21 months.

Observations pertaining to seed germination and seedling growth were found most promising with sealed plastic container with silica gel followed by tin, earthen pot, polythene bag and muslin cloth bags container. Charturvedy *et al.* (1999) studied that the neem seed exhibited maximum germination (92.8%) followed by the seed sun-dried for one day. Fresh seeds stored in airtight container were viable for longer period as compared to seeds stored in cold storage. Higher values in respect to growth and biomass were recorded in the seedlings which germinate from fresh seeds.

Khera *et al.* (2000) studied the effect of seed collection date, storage, container and storage temperature on germinability of neem (*Azadirachta indica*). They reported that germination of seeds was significantly influenced by the time of seed collection. Seeds collected during July 7 to July 17 exhibited greater germination. Seeds stored in open conditions or in perforated cardboard box at room temperature indicated greater germination and longevity.

Bhardwaj *et al.* (2001) observed that the seeds of *Ulnus laevigata* stored in polythene bags and kept at 5⁰C + 10⁰C maintained 62% germination after four month of storage.

Prakash and Nautiyal (2001) reported that excised seeds of *Polygonum rumicifolium* stored at room temperature (12-20⁰C) and refrigerator (4-6⁰C) showed better germination. Pushkar and Babeley (2001) reported that the seeds stored in sealed container (glass bottle) at room temperature gave good germination and better values of germination velocity index (GVI) then other containers and conditions. Rawat *et al.* (2001) reported that the seeds of *A. exelsa* exhibit orthodox storage behavior as viability period increased with the decrease in storage temperature and seed moisture content.

Sharma *et al.* (2002) reported that seeds of *Toona ciliata* loose their viability when stored at 18-20⁰C, while they retain viability (90%) up to 1 year when stored at (6-8⁰C).

Purohit and Jamaluddin (2003) observed that the seeds of *Pongamia pinnata* stored in plastic jars and polythene bags gave better germination during whole storage period.

Charturvedi and Das (2004) reported that the seeds of *Acacia auriculiformis* and *Acacia nilotica* can be stored for 6-8 months in gunny bags and 10-12 months in air tight plastic containers with good germination percentage (>60%) at room temperature.

Sharma *et al.* (2004) reported that seeds of Tibetana see buck Thorn can be stored up to one year at ambient temperature without any reduction in seed viability. Handa *et al.* (2006) reported effectiveness of containers for storing *P. pinnata* seeds and reported that seeds of species can be stored upto 12 months in airtight plastic container and polythene bags.

2.5 Seed viability:

Seed viability determines ultimate germination and longevity of seeds in storage. Several reports are available to indicate that seed viability varies with the species.

Tela (1983) reported that the neem seed loose its viability after two weeks, but it can retain viability for 12 months in dry, low temperature storage. Rao *et al.* (1984) reported viability of *Populus ciliata* seeds only up to 12 days, when freshly collected seeds were stored in the polythene bags under laboratory conditions.

Maithani *et al.* (1987) reported that seeds of *Holoptelia integrifolia* rapidly lose viability if not properly stored. Under field conditions, seed deterioration can be inhibited up to certain extent provided sealed containers are used for storage preferably with silica gel.

Prasad and Jalil (1987) stored Sal seeds in air -tight polythene bags for about two months to test their viability. It was observed that the deterioration in Sal seed takes place very fast unless it is properly stored. Severe insect damage to Sal seeds appears to be responsible for the loss of seed viability. Khullar *et al.* (1991) reported that neem seeds loose viability within a fortnight of ripening.

Bhagat and Singh (1994) revealed that the acid scarified seeds of *Dodonaea viscosa*, *Indigofera gerardiana* and *Rubus ellipticus* stored in paper bags (100 gauge) and closed glass bottles at normal room temperature retained good viability upto 11, 17 and 6 months. Similarly, *Coriaria nepalensis*, *Berberis* and *Debregeasia hypoleuca* seeds stored in closed glass bottles at ambient room conditions appeared to have good storing ability exhibiting good viability up to 14 and 24 months.

Sah and Singh (1995) studied the effect of temperature and storage in *P. ciliate* seeds on seed germination. The results indicate that the maximum germination was obtained at 20°C. The seeds stored at 2°C retained better viability (60.5%) than the seeds stored at -10°C (30.0%) after one year of storage period.

Purohit *et al.* (1996) studied that the Tetrazolium test confirmed 100 percent seed germination of *Butea monosperma*, *Pongamia pinnata* and *Terminalia bellerica* up to 18 months of storage.

Choubey *et al.* (1997) reported 70-80% viability when determined by cutting test and 70-75% seeds were found viable as determined by TTZ test in *Buchanania lanzan*.

Negi and Todaria (1997) found that heavy and large seeds of *T. bellerica* and *Acer oblongum* performed better in terms of germination, while *T. bellerica* and *T. tomentosa* gave better results in terms of seedling development after 3 and 6 months, respectively. Ram Prakash (1998) reported that Chironjee seeds lying on the ground and exposed to sun either fail to germinate or loose viability.

Punam *et al.* (2002) studied the effects of storage materials (cloth bag, paper bag, polyset bin, polyethylene bag, aluminium foil, and cloth bag in desiccators) on the germination and viability of zinnia (*Zinnia elegans*) seeds in October, December, and February. Seed germination was not observed in October and December, which may be due to the dormancy of Zinnia seeds during winter. In February, the highest germination was observed in seeds stored in cloth bags in desiccators (60.00%) and aluminium foil (57.36%).

Singh *et al.* (2002) packed newly collected seeds of aonla (*Emblica officinalis* [*Phyllanthus emblica*]) with 10% moisture content in cloth bags, plastic bottles, glass jars, paper bags, and 300-gauge polyethylene bags and stored for 22 months under ambient conditions. Seeds stored in sealed polyethylene bags maintained higher percentage of seed viability and germination percentage. The loss in germination percentage was more pronounced in seeds stored in non-airtight containers.

Sharma *et al.* (2004) reported excellent storability on seeds of *Hippophae tibetana* schltre. The seeds retained high good viability even after one year at ambient temperature when stored in plastic container. They obtained 98.5% to 99% seed germination after six and one year of storage.

Sankhyan and Sehgal (2006) reported that seeds of seabuckthorn remain viable for one year under ordinary storage. Cold water treatment (6 days) is recommended to enhance percentage (95.83) and for higher germination value (47.20) after one year of seed collection. In cold storage conditions, the seeds of *Hippophae rhamnoides* L. may retain viability for many years. Handa *et al.* (2007) reported about 53.3% viability for *P. pinnata* seeds after 12 months when stored in airtight containers.

2.6 Effect of pH:

The germination of seed and seedling growth is strongly influenced by different pH level.

Ahlawat and Dagar (1980) investigated the effects of pH, light qualities and some growth regulators on seed germination of *Bidens biternata*. At pH 2.5 there was complete inhibition of germination but the germination percentage gradually increased from pH 3 to pH 7. Again in the basic medium there was decline and at pH 9 percentage germination was again zero. Tomar and Yadav (1980) reported the effect of saline irrigation water of varying EC, SAR and RSC levels on germination and seedling growth. Root length of all forest species was reduced and mortality increased by increasing EC, SAR and RSC when compared with control. All species were found sensitive to saline water at the early stages of germination.

Koller and Hadas (1982) studied that the seed germination is difficult in barren and degraded land, where lot of stress conditions are available, water scarcity and high pH are one of them. Mandal and Handoo (1998) investigated tolerance limit of salinity stress on germination of Subabool seeds using distilled water and tri-salt solution of NaCl, CaCl_2 and Na_2SO_4 in concentrations of 0, 4, 8, 16, and dsm^{-1} . They reported decline and delay in germination at all the levels of salinity to be associated with decrease in the values of germination, relative index, germination value, mobilization efficiency, vigour index and shoot-root ratio. Mishra *et al.* (1988) germinated seeds of 4 species at 7 (control), 9, 10 and 11 pH. They reported that percentage germination recorded one week later was not significantly different

between treatments. Although ranges varied for *Albizia lebbeck* 40-60%, *Leucaena diversifolia* 80-93%, *Pongamia pinnata* 33-63% and *Prosopis juliflora* 63-76%. Sah *et al.* (1989) studied that the rate of germination for *Pinus roxberghii*, *P. wallichiana*, *P. patula*, and *P. greggii* was higher at pH 5, 6 and 7 as compared to pH 4 or 8.

Singh (1992) observed the performance of *P. pinnata* and *A. curniganoil* at varying salinity (ECe) level and exchangeable sodium percentage (ESP) levels. Both the species failed to grow at and above the levels of ESP 30.6, whereas under saline conditions *P. pinnata* failed at ECE 32.5 dsm⁻¹ and *A. curnighani* at and above ECE 16.3 dsm⁻¹.

Lacey and Line (1994) found that pH above 8.5 was detrimental both to total number of germinating seed and seedling survival. Srinivasu and Toky (1996) while studying seed germination and seedling growth of *Acacia nilotica*, *Albizia lebbeck*, *Pithecelobium dulce* and *Prosopis juliflora* under alkalinities of sodium carbonate and sodium bicarbonate for 30 days in solution and soil culture reported that the seed germination decreased and delayed with increasing alkalinities.

Masilamani *et al.* (2002) was conducted to determine the effect of different soil pH and organic matter on germination, seedling growth and chemical attributes of *Pongamia pinnata*. The seeds were sown in soil with different pH (8.1, 9.0, 10.2 and 10.5) and the different pH soil mixed with sand+farmyard manure at 2:1:1 ratio compared with control (red earth+sand+farmyard manure at 2:1:1 ratio). Significant differences were observed among different treatments for all the parameters of germination and seedling growth of 28 days old seedling and survival percentage, seedling growth attributes and chemical constituents (Chlorophyll a, b and total) and total N, P and K content of 180 days old seedling.

Dagar *et al.* (2004) studied the seed germination of *Salvadora persica* and *Jatropha curcas* in solutions of different pH (pH 2-11) and salinity. Seed germination was highest at pH 8.0 for both species. The germination was faster at pH 6-8 compared to other levels. The seed germination was initiated after one week when seeds were treated with saline water of electric conductivity of 2 and 4 dS m⁻¹ in both species.

while on higher salinity, germination started during second week. The seed germination was lower at higher salinity.

2.7 Effect of water stress:

Seed germination and seedling growth of many species are influenced by water stress condition. There are reports that seed germination is quite poor in water stress condition.

Mc Donough (1979) reported that the initiation of germination was also delayed by increasing water stress conditions in *Populus tremuloides*.

Wilson (1971) and Sah *et al.* (1989) reported that increase in water stress may reduce the water uptake, there by retarding the initiation of various metabolic processes due to degradation and activation of essential hydrolytically and other group of enzymes involved in the seed germination. Rao and Singh (1986) compared *Quercus leucotrichophora* A. Camu. (banj oak), and *Pinus roxburghii* Sarg. (Chir pine), for seedling growth as a response to moisture gradients. Under soil moisture stress, both the species attained similar heights, but in terms of dry weight, banj oak performed better. The Chir pine had higher leaf weight ratio (LWR), while banj oak had higher root: shoot ratio, compared to the other.

Landis *et al.* (1989) studied the growth performance of seedlings of *Anogeissus pendula* Edgew. in different water regimes at nursery level. Out of three irrigation followed by daily irrigation conditions. The minimum growth of the seedlings were observed in twice/ a week irrigation conditions.

Sah *et al.* (1989) found that due to increase in water stress from -5 to -15 bars, suppression in germination was high in *P. greggii* and *P. patula*, while *P. roxburghii* was relatively little affected. Nautiyal *et al.* (1996a) studied the effect of water stress and some antitranspirants on the chlorophyll contents of the leaves of *Pongamia pinnata* (L) Pierre, under controlled laboratory conditions. The chlorophyll a, b and total, invariably increased from daily to fortnightly watering interval, however, there was a sharp decrease in case of monthly watering interval. The chlorophyll a, b, ratio

was maximum at weekly watering interval, minimum at monthly watering interval. It shows that the mild stress effects the formation /accumulation of chlorophyll b more than chlorophyll a (weekly watering interval) however, heavy stress destroy both chlorophyll a and b with the result less photosynthesis and low growth (monthly watering interval).

Nautiyal *et al.* (1996b) studied the effect of water stress and some antitranspirants on the survival, growth and dry matter production of *Grevillea robusta* A. Cunn. under controlled laboratory conditions. In general, the survival percentage, height of plants, number of branches per plants, fresh and dry mass of roots, stem, branches and leaves decreased with increasing water stress irrespective to control (untreated) as well as in all antitranspirant treatments. However, the effect was more prominent under antitranspirant treatments. Commonly the decrease in the said parameter was sharper from daily to weekly watering interval than fortnightly interval. No seedlings could survival under monthly watering interval.

Pokhriyal *et al.* (1997) studied the response of *Acacia nilotica* to 4 watering schedules (daily, weekly, fort nightly) in pots using 3-month- old seedling marked reductions in plant height, root length, basal diameter, fresh and dry weights of leaf, stem root and nodules, as well as nitrogenous (acetylene-ethylene reduction) activity was observed with the increase in the time interval between watering.

Jha and Chaudhary (1998) studied the effect of different watering frequencies (intervals of 1, 4 or 7 days) on polybag seedlings of five MPTs in the nursery. Survival and growth of *E. citriodora* and *Casuarina equisetifolia* was poor even at the 1 day watering interval (40%) but growth was good. The other three species (*Acacia senegal*, *Albizia lebbeck* and *Dalbergia sissoo*) survived much better (87-100, 93 and 87-93% respectively. The Species order for root growth was *Albizia lebbeck* > *Acacia Senegal* > *C. equisetifolia* > *D. sissoo*. Growth differences between watering frequencies were only significant for *Albizia lebbeck* (height and roots) and *C. equisetifolia* (height).

Ndour and Danthu (1998) studied the seed germination in 9 species of *Acacia*. *A. nilotica* was the most susceptible to both water & salt stress, and *A. senegal* and *A. raddiana* were the most tolerant. *A. dudgeoni* (the most shade demanding species) and *A. ebrenergiana* (the most drought-tolerant species) exhibited the same level of tolerance to the imposed stress conditions.

Saxena *et al.* (1998) studied that the water stress conditions (-5, -7.5, -10 and -16 bar) caused inhibition of seed germination. The inhibitory effect of water stress was most in *P. pinnata*, intermediate in *Acacia auriculiformis*, *A. catechu*, *A. nilotica*, *Albizia lebbek*, *Casuarina equisetifolia*, *Dalbergia sissoo* and *Prosopis juliflora*, and least in *Leucaena leucocephala*. The rate of germination under water stress conditions was less inhibited in *L. leucocephala* and *Acacia nilotica* than in the other species tested.

Fanti *et al.* (2000) conducted a study to evaluate the efficiency of osmotic conditioning increased tolerance of *Chorisia speciosa* seeds to water stress and accelerated aging. The primarily scarified seeds were primed in KNO₃ (0.1M) solutions at 20°C for 24 h. Primed and non-primed seeds were exposed to water stress simulated with PEG 6000 solutions with 0.0, -0.1, -0.2, -0.3, -0.4, -0.5, -0.6 and -0.7 MPa of osmotic potentials and to accelerated aging at 45°C and 100% RH for 0, 24, 48, 72, 96 and 120 h. Results showed that the mean values of germination rate and germination percentage were higher for primed seeds than the non-primed ones. The tolerance limit to water stress was extended for primed seed.

Aziz *et al.* (2001) studied the seed germination and growth of *Acacia raddiana* and *A. nilotica* seedlings under induced water deficit and salinity conditions. Different concentrations of either sodium chloride or mannitol (0.1, 0.2, 0.3 and 0.4 M) were used to induce salt and drought stresses. *Acacia raddiana* was more tolerant to drought stress than *A. nilotica*.

Perez *et al.* (2001) observed that the seed of canafistula seeds germinated faster in manitol than in PEG solutions, PEG or manitol was in between -1.4 and -1.6 MPa. Humara *et al.* (2002) observed that the excess deficit of water delayed the germination

enhance the performance of Mediterranean *Quercus* seedlings through species-specific mechanisms.

2.8 Effect of light:

The influence of light has a great significance on the growth of seedlings, as it is the only source of chemical energy by photosynthetic carbon assimilation for use in various life processes. The researchers on this important aspect have been done by many investigators.

Ahlawat and Dagar (1980) studied the effect of light qualities on seed germination of *Bidens biternata* a medicinal herb. Red light prompted seed germination, yellow and combination lights showed little effect while blue and green lights inhibited. Sah *et al.* (1989) studied that the germination of *P. roxberghii*, *P. wallichiana* and *P. greggii* was greater in light than in dark. Teketay (1996) studied the effect of light on the germination of *Tamarindus indica* seeds. Seeds germinated both in light and dark (98%) condition.

Silva and Mathos (1998) reported that the seeds of *Triplaris surinamensis* germinated better under white (69-73%) & red light (65-66%) than under far red or no light (both 50.51%). Naidu and Amritphale (2001) studied that the seeds of *Caesulia axillaries* Roxb. displayed an absolute light requirement for germination after harvest and showed germination response with R (red light), FR (far-red light), R-FR, R-FR-R and B (blue light) irradiations. Single red light exposure could induce germination of more than 70% of the seeds. Dagar *et al.* (2004) studied the seed germination of *Salvadora persica* and *Jatropha curcas*. Maximum seed germination was observed for both species under natural light, followed by yellow, green, red and blue lights.

2.9 Effect of temperature:

Various tree species respond differently to temperature during germinations. Kumar and Bhatnagar (1976) conducted an experiment to determine the effect of

different temperatures and substrates on the seeds of *Dalbergia sissoo* Roxb. These two factors significantly influence the germination behaviour of this species. Among all the treatments, the maximum and quicker germination was obtained at 30°C in 'Between Paper' (BP) in nine days time for both fresh and one year old seed lots. The alternate temperatures between 20-30°C, 25-35°C and 30-40°C were also found to be equally effective for germination of seeds. Temperatures at 40°C and 35-40°C were not favourable for germination in comparison to other temperatures. Gupta and Kumar (1977) studied the effects of five constant and three alternating temperatures viz, 20°C, 25°C, 30°C, 35°C, 40°C, 20-30°C, 25-35°C and 30-40°C in combination with five moisture levels of substratum viz, 25%, 50%, 75%, 100% and 125% on the germination of *Dendrocalamus strictus* seeds. It was observed that 30°C is the ideal temperature for germination since this brought out the maximum and quickest seed germination. 40°C was found to be detrimental for germination. 20°C was also not found to be favourable as the rate of germination at this temperature was slow.

Alternating temperatures also did not record any edge over constant temperatures. Moisture status of substratum was found to be a controlling factor. 125% moisture at all temperatures proved fatal and 25% moisture in most of the cases was observed to be insufficient to bring in the desired level of hydration, 50 to 75% moisture level was recorded to be the optimum.

Chamshama and Downs (1982) reported that a temperature of 25°C in light, 30°C in light and 30°C/20°C in light or dark gave significantly higher germination percentages in *Chlorophora excelsa* seeds. Germination was significantly retarded by a constant temperature of 35°C in light and 30°C in dark. Sah *et al.* (1989) observed that the *P. roxberghii*, *P. wallichiana* and *P. patula* indicated maximum germination at 25°C. Negi *et al.* (1994) studied that the maximum seed germination occurred under 30°C in *Pinus patula*.

Thailiyal and Rawat (1991) reported that germination in *Alnus nepalensis* and *Alnus nitida* commenced on the 7th day and was completed by the 28th day. Maximum germination was recorded at 25°C. Seed emptiness was found to be major causes of

poor germination in both the species. Seeds of both the species were found short lived in nature. Mosseler *et al.* (1993) reported that seeds of *Acer oblongum*, *Anogeissus latifolia*, *Kydia calyeiana*, *Sapindus mukorossi*, *Terminalia bellerica* and *T. chebula* were germinated at different temperatures of 10, 25 and 30°C. No germination was recorded at 10°C. Temperature increased to 25°C after 10 days significantly improved germination in all 6 species. Omari (1993) reported that the best germination occurred at 15°C in *Acacia* Spp. Negi *et al.* (1994) reported maximum germination in *Pinus patula* at 30°C. Kausik *et al.* (1995) reported that the seed germination was 100% for all treatments at 20, 25 and 30°C.

Negi and Singh (1995) investigated that maximum germination was recorded in *T. bellerica* at 25°C and 30°C constant and 25/20, 25/30 and 30/25°C alternative temperature and minimum was recorded in *T. chebula* at 20°C constant and 20/25°C alternative temperature. Shah and Singh (1995) reported maximum germination in *Populus ciliata* at 20°C.

Tekety (1996) studied that the in case of *Tamarindus indica* germination was totally inhibited at 10°C while it ranged between 84-98% at 15-30°C. Optimum temperature for germination (98%) is around 25°C. Lima *et al.* (1997) found that the seed germination in *E. contortisiliquum* was minimum in between 10.9 to 11.9°C and maximum in between 40.9 and 42.4°C. The germination rate increased with increasing temperature.

Al-Mudaris *et al.* (1998) reported that increase in temperature from 15°C to 30°C improved seed germination and reduced days taken to initiate and complete germination in *Acacia* spp. Borges *et al.* (1998) reported that 30°C favored the germination and seedling growth of polyembryonic varieties of mango-Espida and uba under laboratory conditions. Negi *et al.* (1998) reported that the maximum seed germination occurred under 30°C. Silva and Mathos (1998) reported that light and temperature effect seed germination in *Triplaris surinamensis*. White and red light at 25 and 30°C resulted in satisfactory germination (65-73%). Naidu *et al.* (1999) reported 84-88% germination in *Sapindus trifoliatu*s when seeds were incubated at

60°C for 1-5 hours. Teketay (1999) studied the seed germination of *Dscopodium penninervium* incubated at alternating temperature of 20/12 and 30/12°C under continuous light. Seed germination was 89 and 61 to 44 and 50% respectively.

Andrade *et al.* (2000) reported that constant temperatures of 25, 30 and 35°C gave the best germination in Genipap (*Genipa America*). Shringirishi *et al.* (2001) reported that maximum germination percent and mean daily germination (MDG) was obtained at 30°C in neem (*A. indica*) seeds. Yirdaw and Leinoenen (2002) observed that germination probability of *C.africana* seeds increased as temperature increased from 15 to 30°C. Keblawy and Rawai (2004) studied seed germination in *Prosopis juliflora* and revealed that germination decreased significantly with the increased temperature. Optimal germination percentage occurred at 25°C.

2.10 Effect of time on sowing:

The time of sowing is also important so as to get maximum germination and healthy seedlings for plantation. Prasad *et al.* (1988) reported that May is the best month for *Buchanania lanzan* sowing with 15.5% germination after 20 days of sowing and completes within 26 days. Further there was no germination in July. In Mango sowing time is reported to be June-July under north Indian conditions (Anon, 1985). Bhagat *et al.* (1993) reported that the seed sowing should be undertaken immediately after seed collection in *Prunus cornuta*. Bhardwaj and Chakraborty (1994) found that the *Terminalia bellirica* and *T. chebula* seedling growth were better in the nursery when seeds were collected in first fortnight of January and sowing was done at last and third week of March respectively.

Morris *et al.* (2000) reported the effect of sowing date, and shade on germination of *Swietenia macrophylla* in a nursery. Seeds were sown on four different dates, spanning the dry season to the middle of the rainy season. Germination increased linearly with increasing shade. Seed sown in August did not germinate. Beniwal *et al.* (2004) reported that time of seed sowing greatly influenced germination and seedlings growth in *Jatropha curcas*.

2.11 Effect of depth on sowing:

A number of factors are responsible for low germination percentage in the nursery and the depth of sowing to be an important consideration in raising nursery.

There are some reports that reflect that sowing of seeds at proper depths is essential for the successful seedling emergence and subsequent growth. Singh *et al.* (1973) conducted the experiments on the effect of depth of sowing on germination of Kail seeds and reported that sowings done up to 15 millimeter depth give higher germination percentage than deeper sowings. Sowing of Kail at a depth of 15 millimeter is recommended and sowing deeper than 25 millimetres should be avoided. Singh *et al.* (1975) studied that the effect of the depth of sowing on germination of spruce seeds and reported that the germination percentage decreased as the depth of sowing increased; the decrease being very much marked with sowings done at a depth of 15mm and more. Deeper sowings delayed germination and the number of days taken for the commencement of germination increased with an increase in depth of sowing. The results of these experiments show that spruce should be sown as shallow as possible and in no case deeper than 10mm. Bhatia and Chauhan (1983) reported that germination of Deodar increased as the depth of sowing increased from 5mm. 10mm. Chandra and Ram (1980) reported that the germination increased as the depth of sowing increased from 5mm to 10mm in Deodar seed.

Sowing deeper than 15mm delayed germination significantly. 10mm depth is recommended for sowing of deodar seed. Anon (1981) reported that 30% plants can be obtained by direct sowing at a depth of 0.6cm at the commencement of the monsoon rains in Uttar Pradesh.

Tripathi and Bajpai (1985) tested the seeds of Kardhai (*A. pendula*) to study the effect of the depth of sowing on germination. The percentage germination increased as the depth of sowing increased from 5mm to 10mm but further increase in depth resulted in decreased germination. Sowing deeper than 15mm delayed germination and also enhanced the completion period of germination. Kardhai seeds

were found to have better germination at a depth of 10mm, which may be recommended to nurseryman.

Singh *et al.* (1985) conducted experiments to study the effect of the depth of sowing on germination of *Populus ciliata* seed showed that sowing on the surface gives the highest germination percentage and even the slightest covering of the seed by sand depresses germination.

Maithani *et al.* (1988) carried out an experiment in the nursery of Silviculture Branch for determining the best combination of method of sowing and optimum depth of sowing and quantity of seeds for afforestation purposes. The results indicated that line sowing and broadcasting is equally effective. The seedling must be protected from frost.

While working on effect of sowing depth in *Pistachia integerima*, Sehgal and Singh (1990) found that 2cm depth is most appropriate for germination. Ponnammal *et al.* (1993) reported that the best depth for germination of Neem seed was 0.5 to 1.0cm.

Arjunan *et al.* (1994) reported that the best depth for germination of *Pongamia pinnata* seeds is 0.5 to 1.0cm. Mutha *et al.* (1995) studied that the *P. juliflora* seeds at about 10mm depth gave the maximum germination. It also gave seedlings of high sturdiness quotient.

Arya and Singh (1996) observed that the seed germination in *Ulmus laevigata* was best (29.8%) at 1cm depth and decreased steadily at greater depths (to only 1.32%) at 4cm depth. Bahuguna and Pyarelal (1996) studied that the effects of shade and mulch on the germination and to determine best combination of soil mixture and proper depth of sowing on the germination of seeds of *Mallus philipensis*. The results indicated that use of shaded bed and germination media in which soil: sand: FYM are in 1:1:1 ratio and seeds sown at 1.0cm depth gave best results in nursery stage.

Agboola (1997) reported that seeds of *Prosopis africana* showed maximum germination and seedling emergence at 2 and 6cm soil depth. Lal *et al.* (1997) reported 1.5cm or 2.0cm was best depth for seed germination of *Michalia champaca*.

Umarani *et al.* (1997) studied the effect of seed size and depth of sowing on germination and seedling growth of *Casuarina equisetifolia*. Both germination and seedling growth and vigour were best in the largest seeds (QR) sown on the surface, followed by the smallest seeds (10p) gave very poor germination (8-10%) and seedling vigour at all sowing depths. The behavior of the medium sized seeds (10R) was intermediate (germination 46-50%). Overall, germination and seedling performance were better in the surface sowing treatments, Further reported that the germination (60%) and seedling growth and vigour in *C. equisetifolia* were best in the largest seeds sown on the surface, followed by the largest seed sown at 1cm depth (58% germination). Masilamani and Dharmalingam (1998) reported that drupes of one year old seedling of teak (*T. grandis*) placing with the scar end up or horizontally at a depth of 1.5-2cm resulted in early and higher germination; more seedlings per 100 drupes, higher root and shoot length and greater dry matter production and vigour. Padma and Reddy (1998) found that time taken for germination in mango was 17.8, 33.0 and 23.4 days when seed placed at depths of 1, 2 and 4cm, respectively. Minimum time taken for 50% germination of seeds at 1cm depth was 29.9 days.

Akinola *et al.* (1999) reported that maximum seed germination of subabul in light soil was obtained at 6cm depth of sowing, while in heavy soil at 2cm depth. Li and Wardle (1999) found that surface sowing gave higher percentage of seedling emergence and more rapid completion of emergence compared with a 1 or 2cm sowing depth in the case of *Hippopal rhamnoides* cv. Indian summer, *H. tebetana*, *H. neurocarpa*, *H. salicifolia* and *H. rhamnoides* sub species *rhamnoides*, *sinensis*, *turkestanica* and *mongolica*.

Pandey and Khatoon (1999) studied the depth and orientation of seeds of *Sterculia Roxb.*, in which seeds were sown in soil at 2cm and 4cm depth in vertical (Micro Pyle end upward), horizontal (Micropylar end sideways) and inverted

Micropylar end downward) orientations. Maximum germination (80%) occurred in horizontal and vertical orientation at 4cm and 2cm depth, respectively. Early emergence and significantly higher seedling vigour occurred when seeds were sown at 2cm depth in vertical orientation.

2.12 Effect of Shade:

Shade is provided in the early stage for proper development of seedlings. Different levels of shading affect the germination percentage. Shading is required during winter, when there is a danger of frost and during summer when temperature is high. The following reports reflect the effect of shade on seed germination and seedling growth. Microclimate in nursery is known to influence seed germination and seedling growth. Shade is one such factor which can be modified to promote seedling growth in nursery. Several workers have worked out effect of microclimate on seed germination and seedling growth. Effect of important microclimatic factors on seed germination and seedling growth is discussed below.

Pathak (1983) reported that seedling of *Leucaena leucocephala* raised under 45% light conditions showed better height and total dry matter. Rao and Singh (1986) compared *Quercus leucotrichophora* A. Camus. (banj oak), a late successional species, and *Pinus roxburghii* Sarg. (Chir pine), an early successional species, for seedling growth as a response to shade and moisture gradients. Chir pine showed wider ecological amplitude for soil moisture, but narrower amplitude for shade tolerance. Under soil moisture stress, both the species attained similar heights, but in terms of dry weight, banj oak performed better. The Chir pine had higher leaf weight ratio (LWR), while banj oak had higher root: shoot ratio, compared to the other.

Beniwal *et al.* (1989) conducted an experiment to see the effect of open, shade and mulch on the germination of *Chukrasia velutina* seeds. The results after analysis of the data indicated that use of mulch produces maximum number of seedlings and gives quicker germination. Beniwal (1990) studied the requirement of optimum light intensities for height and growth of Hollong seedlings. In all 25 treatments three

replications were taken. Among the all treatments T₁₇ (25% overhead and 100% side shade) proved to be the best. It was also observed that side shade played vital role than overhead shade. Beniwal *et al.* (1990) studied that the effect of shade and mulch on the germination of *Toona ciliata*. The results after analysis of the data indicated that seed sown under shade gives quick and higher germination. Beniwal *et al.* (1990) studied that the effect of shade and mulch on the germination of *Adina cordifolia*. The results after analysis of the data indicated that use of mulch gives quick and higher germination

Rao (1991) compared the effect of shade and soil moisture stress on seedling growth of two early successional tree species, *Acer oblongum* and *Olea glandulifera*, found in late successional communities. Under higher shade and soil moisture stress, the seedlings of *A. oblongum* attained more height, and achieved more dry weight, a higher root shoot ratio and lower leaf weight ratio than *O. glandulifera*. The response breadth of *A. oblongum* was wider on the gradient of soil moisture and narrower on the gradient of shade compared with *O. glandulifera*.

Naugraiya and Pathak (1992) studied on the growth behaviour of *Atylosia scarabaeoides* under reduced light condition. 100% light was received from sun directly, while 60, 30, and 10 % light obtained by musline cloth chamber created by keeping different layers of the cloth. Root length and number of nodules were maximum under 100% light while their dry weight was maximum under 30% light condition. The best growth performance of above ground parts was obtained under 30% light conditions. RGR and NAR under 10% light were high with poor dry matter production, followed by 30% light condition with maximum dry weight production. Under the 100 and 60% light condition the RGR and dry matter production was more or less similar. Leaf area ratio was obtained maximum under 60% light during 30 and 60 days growth period. The 10 percent light situation gave minimum LAR.

Naidu and Swamy (1993) reported that *Pongamia pinnata* grown under shade showed decrease in root and shoot growth and biomass production. Net

photosynthetic rate also declined in shade grown plants, while leaf number and area increased.

Negi *et al.* (1994) investigated the effect of temperature and seed desiccation on seed germination and seedling growth of *Pinus patula*. The result revealed that the maximum seed germination occurred less than 30°C. The low shade level and high moisture levels provided best growth to *Pinus patula* seedlings. The root shoot ratio was high at intermediate shade level.

Saxena *et al.* (1995) compared the growth response of seedlings of *D. sissoo*, *A. catechu* and *C. equisetifolia* on shade gradient. The seedling growth in *D. sissoo*, *A. catechu* was maximum under lower shade treatment, while *C. equisetifolia* indicated maximum growth under unshaded control. The values of root shoot ratio were higher for *A. catechu*, *D. sissoo* then for *C. equisetifolia*. Banik (1997) studied the growth response of seedling of *Bombusa tulda* and *Dendrocalamus strictus* under four different light condition (sunlight, partial sunlight, shade, and 6 hours photo period) up to nine months of age. Survival was highest (80-95%) under sunlight & partial sunlight conditions. Brahman *et al.* (1997) studied the effect of growth performance and seed output of *Cajanus cajan* intercrop and it was observed that gradual increase in shade progressively decreased the plant height, number of branches, number of nodules and seed per plant and finally per hectare gain yield.

Chen (1997) reported that expressions of morphological characters in different shade tolerant tree species varies greatly. As such, more tolerant trees show greater plasticity in morphological characters than less tolerant species.

Bosco *et al.* (1998) reported best germination of yellow Mombin (*Spondias lutea*) under 50% shade while giving different presowing seed treatments. Gansert and Sprike (1998) while studying storage and mobilization of non structural CHO and biomass development under different light intensities in *Fagus sylvatica*, reported that plant survives through limited light by way of shift in shoot growth during first half of growing season and suppression of lateral root growth during 2nd half of growing season.

Starch concentration in roots decreased with reduction in light intensity and lateral root growth also reduced. Hewitt (1998) reported that angiospermic species growing in shade produce larger seed than those growing in open conditions. Kuo and Huang (1998) reported that 81% sunlight produces best growth in terms of height, collar diameter and biomass yield on growth of *Michelia compressa*. Root shoot ratio and leaf dry weight ratio showed that more photosynthates would be allocated to the leaf and shoot system in 12% light treatment than 81% light treatment. Energy use efficiency was maximum under 12% light treatment. Mazzei *et al.* (1998) reported that partial shade favours plant growth in terms of height, collar diameter and number leaves. However, root: shoot ratio was smallest in the 90% shaded saplings.

Negi *et al.* (1998) reported that the maximum seed germination occurred under 30°C. The low shade level and high moisture levels provided best growth to *Pinus patula* seedlings. The root shoot ratio was high at intermediate shade level.

Rezende *et al.* (1998) carried out the initial development of seedlings to obtain data relevant to the reclamation of degraded gallery forests. Four different light regimes (0, 50, 70, and 90% of shading) were applied to nursery seedlings of *C. aschersoniana*. The experimental design was randomized with 25 seedlings per treatment. The collar diameter, height and number of leaves were assessed, for all seedlings, five times at 2-month intervals. Dry weight of 10 plants per treatment was assessed at the end of experiment. The highest averages for height occurred in conditions simulating a closed canopy (90% of shading) and gaps (50% shading). The collar diameter showed similar patterns except at the last measurement, where the highest average values were found for gap shading. The distribution of dry matter in roots, leaves and stems was more even under gap light conditions. Therefore, this species should be introduced in the initial phase in a programme for reclaiming gallery forests. Salgado *et al.* (1998) studied the initial growth behavior of *Zanthoxylum rhoifolium* under different shade conditions. Seedlings were grown over 22 months under full sunlight, and in 50, 70 and 90% shade treatments. They

observed that after 20 months, the average seedling height (22.79 cm) occurred with the 90% shade treatments.

Welander and Ottoson (1998) reported that shade effect may be reflected in some season or next season also. Therefore, the species susceptible to low light availability may need additional light in subsequent growth season for survival and growth. Banik (1999) reported delay in clump formation and weak clumps under shade in bamboo nursery plants. Chaturvedi and Bajpai (1999) investigated the effect of different light conditions on germination and seedling growth of some selected forest tree species viz. *Bridelia retusa* (Spreng) *H. antidysenterica* (Wall), *L. parviflora* (Roxb.) and *W. tinctoria* (R. Br.). Seeds were sown in earthen pots filled with a mixture of garden soil, sand and decomposed manure in 2:1:1 ratio. After sowing of seeds, three light conditions viz. semi-shady, shady and full sunlight were considered for the experiment and observation were made at definite intervals. The above studies showed that root length was maximum under semi shady condition in *B. retusa* and *H. antidysenterica*, while in *L. parviflora* and *W. tinctoria* it was maximum in full sunlight. Root shoot ratio was highest under shady condition in *H. antidysenterica*, *L. parviflora* and *W. tinctoria* respectively. The growth of seedlings of *B. retusa* and *H. antidysenterica* was better in semi shady condition *L. parviflora* and *W. tinctoria* was higher in full sunlight conditions.

According to Hinesley *et al.* (1999) one-year-old seedlings of Atlantic white cedar (*Chamaecyparis thyoides*) were grown for 1 year (1995) in a transplant bed at Goldsboro, North Carolina, to determine the effects of factorial combinations of seedlings size (small, 5-10cm tall, or medium 12-18cm tall), shade (with or without 50% shade), and peat amendments on nursery growth and subsequent first- year field performance at pocosin Lakes National Wildlife refuge. Growth in the nursery was improved by shade and peat. Peer *et al.* (1999) reported that certain plants tolerate shade through shade avoidance mechanism which is inheritable character.

Savita *et al.* (1999) investigated that the root length was maximum under semi shady condition in *B. retusa* and *H. antidysentria* while in *L. parviflora* and *W.*

inctoria it was maximum in full sunlight. Root/Shoot ratio was highest under shady condition. *H. antidysenterica* was better in semi shady condition and *L. parviflora* and *W. tinctoria* was higher in full sunlight conditions. Tiwari *et al.* (2000) observed that the root/shoot ratio and plant length was maximum under full sunlight condition in *A. odoratissima*, *D. latifolia*, *P. marspium* and *H. binnata*. Therefore, it could be concluded that species which showed better growth in full sunlight condition may be light demander during early phase of seedling growth.

Davidson *et al.* (2002) observed that the *P. discolor* had a high growth rate, a rapid leaf turnover, a large total leaf area and a high specific leaf area (SLA), coupled with high photosynthetic rate, when grown in full sun light.

According to Vyas and Nein (1999) shade increased plant height, number of nodes, mean inter nodal length and various growth attributes in *Cassia ungistifolia* L. The leaf growth also increased in terms of number, expansion and dry matter accumulation. The promontory effect was more prominent at 25 percent shade; however, the impact of further increase in shade level was marginal. Wen Dazhi (1999) reported that broad leaved species namely *Castanopsis fissa*, *Schima superba* and *Cryptocarya concinna* survived well under shade as well as full sunlight. However, number of branches reduced in shade. Number of leaves was more under shade. Leaf area ratio (LAR) was higher in shade than full sunlight. Morris *et al.* (2000) reported the effect of sowing date and shade on germination of *Swietenia macrophylla* in a nursery. Seeds were sown on four different dates, spanning the dry season to the middle of the rainy season. Germination increased linearly with increasing shade. Seed sown in August did not germinate.

Saju *et al.* (2000) studied the effect of shade on growth of *Tectona grandis*, *Grevillea robusta* and *Ailanthus triphysa* seedlings. The two levels of shade were full sun (0%) and 75% average shade. In *Tectona grandis* and *Grevillea robusta* seedlings, the growth performance was better in full sunlight. On the other hand, *Ailanthus triphysa* seedlings performed well under shade.

Davis and Greenfield (2001) studied the performance of ramp (*Allium icoccum*) seed germination in the open field, mixed deciduous forest, under polypropylene structures, providing 30, 47, 63 or 80% shade, and under a wood lath structure, providing an average of 63% shade. Total emergence was significantly higher in the autumn (43%) than in the spring (35%). The highest emergence rates were observed in the forest (57%) and under the polypropylene structure providing 30% shade (52%). The poorest seed germination was observed in the open field (10%). The longest periods of seedling survival were observed in the forest and under the wood lath structure. Puri and Swami (2001) reported that Neem (*Azadirachta indica* A. Juss) seedlings grown in complete light (800 mol/m²/s) had four times more biomass than those grown in diffused light (200 mol/m²/s).

Campos and Uchida (2002) reported the development of *Jacaranda copaia*, *Hymenaea courbaril* and *Ochroma lagopus* (*O. pyramidale*) seedlings under different shade levels in the nursery. The treatments used in the nursery were: (i.) Two treatments with 50% shading during 15 and 30 days, respectively and the remaining period under full sunlight (0% shade); and (ii.) Three treatments under 30, 50 and 70 % shade, respectively by using black polypropylene screen and observed that the growth of *H. courbaril* seedlings was affected in the 70% shade treatment. The growth of *O. lagopus* and *J. copaia* seedlings increased under shade, but their quality was poor. McLaren and McDonald (2003) studied the effect of shade on seedling survival of *calyptanthus pallens*, *Eugenia* sp., *Hypelate trifolia* and *Metopium brownie*. Seedling survival was lower in un-shaded than shaded plot and in the shaded plots, survival was lower in partially shaded plots than in heavily shaded plots.

Singhakumara *et al.* (2003) studied the effect of shade on seedling growth of four *Syzygium* species. They used different shade level with PDF (photosynthetic photon flux density). The above and below- ground growth of all species increased with increase in amount of PDF. Castro *et al.* (2006) studied the effect of full sun light and moderate shade with the two summer watering regimes (daily and low

alternate days)) on leaf and whole plant traits of 1-year-old seedlings of *Quercus occifera*, *Q. ilex* subsp. *Ballota* and *Q. faginea* grown outdoor for 8.5 months leaf traits included measures of morphology, nitrogen concentration, gas exchange and photochemical efficiency, and measures of whole plant traits included biomass allocation patterns, growth phenology, across-summer leaf area change and relative growth rate (RGR). Moderate shade reduced leaf mass per area, increased photochemical efficiency, maximum carbon assimilation rate (A_{max}) and allocation to leaves, and prolonged the growing period in one or more of the species.

2.13 Potting mixture:

Roy (1986) studied the effect of different soil types on seedling growth of *A. amara* and reported that the healthier seedlings based on several growth parameters like shoot and root length, number of leaves, dry weights of shoot, root and nodule, could be obtained using red soil compared to mixed or black soils. The texture of red soil coupled with its high permeability was found to promote growth of root system and nodulation resulting in better seedlings.

Bahuguna and Pyarelal (1990) carried out an investigation for producing healthy seedlings of *Acacia nilotica* species in nursery. The results revealed that the combination of direct sowing in polybags or sowing in boxes with soil media consisting of soil and sand in 2:1 ratio gave best results up to germination. After germination for better growth of the seedlings Farm Yard Manure should be added in the ratio 2:1:1 (Soil: Sand: F.Y.M.).

Naugraiya and Pathak (1990) studied the growth of *Atylosia scarabaeoides* in nursery in a pot culture with six soil types viz. Black (B), Murrum (M), sand (S), B+S (1:1) and B+M (1:3). Physical and chemical properties viz. water holding, pH, organic carbon, N.P.K., Na, Mg and Ca were analyzed. Dry matter production, RGR, NAR and LAR were computed. Maximum (53.5%) water holding capacity was in Black soil followed by mixtures of black soil with Murrum and Sand in 1:1 ratio and minimum was in pure sand (23.62%). Maximum dry matter production was in B+S

1:1) soil plants followed by Black soil plants and minimum was in pure sand plants, while the RGR and NAR were higher in case of sand and Murrum soil plants. LAR was higher in B+M (1:1) plants from 30 to 90 and from 90 to 180 days. Black soil plants gave maximum LAR. Nodulation was maximum (0.2474g/p) in sand plants and minimum in Black soil plants. (0.0514g/p). Beniwal and Dhawan (1991) studied the germination behaviour of pulped as well as depulped seeds of *Anthocephalus chinensis* and the effect of different soil media and watering methods on the germination and growth of seedlings. The results indicate that sowing of pulped seeds give poor germination compared to depulped seeds. Further, use of soil media and watering with the help of can or fine sprayer gives maximum germination.

Dhar *et al.* (1992) studied the influence of growing media on the growth and dry matter accumulation of *Leucaena* seedling. Farmyard manure was found to be best medium for raising healthy and vigorous seedlings of *Leucaena* in polythene bags.

Gupta (1992) conducted a nursery experiment by mixing different levels of tank silt (0, 5, 10 and 20%), FYM (0, 2, 4 and 6%), nitrogen (0, 10, 20 and 40 ppm as urea) and phosphorus (0, 15 and 30 ppm PO₄, as single super phosphate) to find out suitable mixture for producing healthy seedlings of some arid zone tree species. The study indicated significant influence of mixing tank silt and FYM with sand, on the seedling growth of *Dalbergia sissoo*, *Albizia lebbeck* and *Prosopis cineraria*. Response to nitrogen application was shown only by *Albizia lebbeck*. None of the species responded to phosphate application. The potting mixture producing the best healthy seedlings in this study were, 10 percent tank silt +2 percent FYM for *Dalbergia sissoo*, 10 percent tank silt+4 % FYM +40 ppm nitrogen for *Albizia lebbeck* and 10 percent tank silt for *Prosopis cineraria*. Use of tank silt improved the aggregation and the mixture remained intact with the seedling when polythene bag removed.

Bahuguna and Lal (1993) raised *Acacia auriculiformis* seedlings in different soil media in different containers. The results of this investigation revealed that the

Seedlings could be raised in either nursery beds or wooden boxes by dibbling the seeds at 1cm depth or by direct sowing in polybags. The soil media (soil and sand) should be in 2:1 ratio. Farm yard manure could be added later on at transplanting stage for better growth of the seedlings. Bahuguna and Pyarelal (1993) reported that *Acacia caven* is an important species for soil conservation and establishment of sand dunes in arid and semi arid areas. Nursery trial has brought out that the seeds should be sown in soil mixture containing soil and sand in 1:1 ratio at 1cm depth for optimum germination. For better growth, seedlings should be grown in soil, sand and F.Y.M. mixture in the ratio 2:1:1.

Lal and Karnataka (1993) studied the effect of orientation and different ratio of soil mixture on germination behaviour of *Quercus serrata* seed in nursery. Three positions of seed sowing i.e. vertical (embryonic end upward and downward) and horizontal were used. Seeds were sown in four different ratios of soil mixture. Results revealed that *Quercus serrata* seedlings can be raised by sowing the seeds in horizontal position in the soil mixture consisting of soil, sand and farm yard manure in 2:1:1 ratio in perforated polythene bags or in nursery beds for better germination.

Laila and zarad (1994) studied some growth parameters of *Jatropha curcas* seedlings in different soil mixtures. The clay and sand mixtures gave the highest percentage of germination (>80%) and the second fastest germination was obtained with the sandy soil. Clay sand resulted in the greater seedling height, stem diameter and number of branches, but clay resulted in the highest number of leaves and total leaf area.

Shamet *et al.* (1994) conducted study on Chilgoza pine (*Pinus gerardiana* Wall.) to see the effects of potting mixture, fertilizer and mulching on the seedling performance. Soil, sand, moss and FYM (1:1:1:1) gave maximum height (23.67cm), while soil, sand and moss in equal proportion resulted in larger caliper growth (1.24cm) of seedling performance. Maximum 79% survival of the seedlings was achieved in ½" layer sawdust mulch whereas, height and caliper growth were best in ½" layer mulch collected from Chilgoza forest. Sudhakara *et al.* (1995) conducted an

xperiment to determine the effect of seed size, farmyard manure and fertilizer in the rooting medium on the growth performance of containerized seedlings of *Ceiba pentandra*. Seedlings from large sized seeds showed significant increase in height, root collar, diameter and number of leaves. Rooting medium containing sand, soil and farmyard manure in the ratio 1:1:1 was significantly better than rooting medium with sand and soil in the ratio 1:1. Advantage of fertilizer application was negligible. Study of the main effects as well as the interaction effects showed that farmyard manure in the rooting medium is the most dominant factor influencing the seedling performance. Bahuguna and Pyarelal (1996) studied that the effects of shade, mulch combination of soil mixture and proper depth of sowing on the germination of seeds of *Mallus philippensis*. The results indicated that use of shaded bed and germination media in which soil: sand: FYM are in 1:1:1 ratio and seeds sown at 1.0cm depth gave best results in nursery stage. Srinivasu and Toky (1996) studied seed germination and seedling growth of *Acacia nilotica*, *Albizia lebbbeck*, *Pithecellobium dulce* and *Prosopis juliflora* under alkalinities of sodium carbonate and sodium bicarbonate for 30 days in solution and soil culture. The seed germination decreased and delayed with increasing alkalinities and it was significantly ($P < 0.05$) lower in soil culture than the solution culture. The seed germination and seedling growth occurred up to pH 10.0 in *A. lebbbeck* and *P. dulce* while it continued up to pH 11.0 in the remaining two species.

Chakrabarti *et al.* (1998) reported that a good potting medium is characterized by light weight, easy blend ability, good water holding capacity, drainage, porosity, slight acidity, low bulk density free from fungal spores and insects and low inherent fertility etc. Chakrabarti *et al.* (1998) suggested that the physical attributes may be further improved upon by addition of inorganic components like sand, vermiculite etc. Jones (1998) reported that preparation of a suitable potting medium includes standardization of texture and nutrient status. There can be variation from nursery to nursery.

Srivastava *et al.* (1998) reported that apart from the selection of proper gradients, it is necessary to maintain the porosity of the potting mixtures, so that proper development of root takes place. Venkatesh *et al.* (1998) observed that the efficiency was determined by bio fertilizer inoculations with rhizobium, phosphor bacteria and vesicular arbuscular mycorrhiza (VAM), individually and in combination on the growth, biomass, biochemical parameters and nutrient yield of Pungam seedlings under nursery condition.

Srivastava and Bhel (2002) studied the growth of seedlings of *T. arjuna* in different potting media. The treatments consisted of four potting media: sand (T₁), sandy loam soil (T₂), alkaline soil mixed with sand 4:1 (T₃) and soil as in T₃ with additional amendment of farm yard manure, 4:1:1(T₄). Seedling grown in sand (T₁) showed the poor performance and improved in T₃ and T₄ producing seven to eight times greater biomass compare to T₁ and T₂ treatments.

Rathore *et al.* (2004) tested seven combinations of potting mixture ingredient (sand, soil, compost, burnt, rice husk and charcoal) for the production of quality planting stock of *Casuarina equisetifolia* simultaneously, four different volumes (90cc, 150cc, 270cc and 300cc) of root trainers were tested for suitability of container size. Chemical and physical analysis of potting mixture ingredients were carried out for better understanding of nutrient status, porosity, water holding capacity, bulk density, pH and conductivity. The best seedling growth of five months age in terms of height (47.39cm), collar diameter (3.08mm), total dry weight (4.5g), shoot dry weight (3.04g), root dry weight (1.47g) and quality index (0.26) was observed in potting mixture consisting of sand, soil, compost, burnt rice husk and charcoal in the 30:10:50:5:5 ratio, which was at par with potting mixture consisting of sand, soil, compost in the ratio of 20:20:60. Larger size of containers (300cc) at three months age produced seedlings with maximum height (27.61cm), collar diameter (2.08mm) and dry biomass (4.75g), but had other disadvantages like more sturdiness quotient (13.67), less root shoot ratio (0.43) and no proper plug formation after 3 months. On the other hand seedlings raised in 150cc root trainer resulted into low sturdiness

quotient (11.18), more root shoot ratio (0.62) and good plug formation and considered for planting.

Material and

Methods

MATERIAL AND METHODS

3.1 Study Site:

The study was conducted at National Research Center for Agroforestry, Jhansi during 2005-06 to 2006-07. Jhansi at an elevation of 300m above the mean sea level and situated between latitude 25°11'-26°27'N longitude 78°17'-81°34'E with annual precipitation of 936mm of which 80-90% is received during July-September. The climatic pattern of Jhansi is true representative of semi-arid region with mean maximum temperature ranges from 22°C-47°C and minimum from 2.5°C to 29.9°C.

Meteorological data for the years 2005-2006 and 2006-2007 are presented in Annexure-I. During the period, the maximum and minimum temperatures recorded during 2005 were 43.1°C in May and 5.2°C in December. The maximum and minimum humidity recorded were 90.8% in September, 2005 and 24.5% in November, 2005. The highest amount of rainfall 214.6mm was recorded in the month of July and minimum 1.2mm during December, 2005. There was no rainfall in the month of May and November, 2005. The maximum and minimum number of rainy days recorded were 14.0days on July, 2005 and 1day on February and March, 2005 (Annexure-I).

However, the maximum and minimum temperatures recorded were 41.8°C on May, 2006 and 6.2°C on January, 2006 (Annexure-I). The maximum and minimum humidity recorded were 90.8% in January, 2006 and 25.2% in April, 2006. The highest amount of rainfall 138.6mm was recorded in the month of July and minimum 0.8mm during April, 2006. There was no rainfall in the month of January, February, October and November, 2006. The maximum and minimum number of rainy days recorded were 9.0days in July, 2006 and 1day in December, 2006 (Annexure-I).

The maximum and minimum temperatures recorded were 41.7°C in May, 2007 and 6.0°C in December, 2007. The maximum and minimum humidity recorded were 90% in August, 2007 and 23% in April, 2007. The highest amount of rainfall 143.3mm was recorded in the month of June and minimum 1.8mm during January,

2007. There was no rainfall in the month of March, October and November 2007. The maximum and minimum number of rainy days recorded were 13 days in July, 2007 and 1 day in December, 2007 (Annexure-I).

The laboratory experiment was conducted in the laboratory and the field experiment was carried out in nursery of this institute. The details of the materials and methodology adopted are described in this chapter.

3.2 Seed Collection:

The fresh seeds for the study were collected from the different parts of Lalitpur district during the month of November 2004 and 2005. The fruits were removed and seeds were collected and stored at room temperature. The seeds were used for conducting different experiments as detailed in the following sections.

3.3 Experimental Details:

The study was conducted in two parts as detailed below:

Part (A) Laboratory Studies:

3.3.1: Effect of storage containers and duration on seed germination:

To study the effect of storage conditions and duration on seed germination and seedling growth, fresh seeds were collected. As per the technical programme fourteen hundred seeds were kept in each six types of storage containers (Air tight plastic Jar, Plastic bag, Paper bag, Cloth bag, Earthen pot and Gunny bag *i.e.* control) for seven durations (0 months, 2 months, 4 months, 6 months, 8 months, 10 months and 12 months) to test the longevity and germination of seeds and its effect on seedling growth. The containers were kept in dark at room temperature. Twenty five seeds each for TTZ test and for seed germination test from in each replication were taken randomly.

The experiment was conducted in Completely Randomized Design with four replications at room temperature in the laboratory. Requisite amount of distilled water

was supplied to each Petri dish to maintain the moisture. Visible plumule and radicle growth was used to define germination. Germination was recorded daily and allowed to proceed for 30 days. The following observations were recorded.

(i) Viability of seed (TTZ test):

The seed viability was tested by using tetrazolium test (TTZ) as described by Purohit and Jamaluddin, 2003. It is quick and reliable method of determining seed viability. The principal of the TZ test is based on the response of all living cells of the seed which can reduce a colourless solution of 2, 3, 5 Triphenyl Tetrazolium Chloride (TTC) into a red coloured compound called formazan. The reduction of the chemical takes place in the seed by the action of a group of enzymes known as dehydrogenases. These enzymes are involved in H transfer during respiratory activity of biological systems. Since the reaction takes place within the respiring cells and the formazan is non diffusible, a clear topography of living and non living tissues within the seed is developed.

For Tetrazolium test, the 0.5 per cent solution was prepared by dissolving one gram of tetrazolium powder in 200ml of distilled water. The seeds were first washed to remove any traces of the fungicides etc. and then soaked for 12hrs in water at room temperature. The softened seeds were cut longitudinally from the distal end towards the base, parallel to the plane of the embryo into two halves. The seeds were soaked in solution of tetrazolium salt for 48 hrs at room temperature in covered Petri dishes. Live cells stained red whereas dead cells remained unstained. The following observations were recorded.

(ii) Number of days taken to initiate germination:

Days taken to initiate germination were counted from the date of placing seeds into Petri dishes to the date of radicle emergence and expressed in number.

(iii) Number of days taken to complete germination:

Days taken to complete germination were counted from the date of placing seed into petri dishes to the date of last seed germination and expressed in number.

(iv) Germination percentage, Mean daily germination and Germination value:

(a) Germination percentage:

Germination count was recorded daily, starting from the date of first germination till the end of germination. Germination percent of the seeds was calculated using following formula.

$$\text{Germination\%} = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds sown}} \times 100$$

(b) Mean daily germination (MDG):

Mean daily germination is calculated by the following formula:

$$\text{MDG} = \frac{\text{Total seeds germination}}{\text{Days taken to complete germination}} \times 100$$

(c) Germination value (GV):

The rate of germination, expressed as germination value (GV), was calculated with the help of following formula (Czabator, 1962):

$$\text{GV} = \text{PV} \times \text{MDG}$$

Where:

PV (Peak value) is the cumulative germination rate, till it begins to slow down, divided by the number of days to reach that point.

(v) Vigour index:

The vigour index (VI) of the seedlings was estimated as suggested by Abdul-Baki and Anderson (1973):

$$VI = (RL + SL) \times GP,$$

Where,

RL is root length (cm), SL is shoot length (cm) and GP is germination percentage.

(d) Root and shoot length (cm): Root and shoot length was measured with the help of measuring scale at the termination of the study.

3.3.2: Effect of pH and water stress on seed germination:

To study the effect of pH levels and water stress on seed germination and seedling growth the experiment was conducted in laboratory. One hundred seventy five fresh seeds were taken for each pH level and water stress level. The seeds treated with distilled water were considered as control treatment. Each treatment was replicated seven times. Observations on seed germination were recorded at one day intervals up to 15 days. Radicle emergence was considered as a criterion for seed germination (Jann and Amen, 1977). The filter paper was moistened with the appropriate solution at alternate days.

The methodology adopted to study the effect of pH and water stress was same. Different pH solutions were prepared using buffer tablets of 5, 6, 7, 8 and 9 pH. pH levels were checked in the laboratory using digital pH meter and adjusted to desired level with the help of distilled water. Thus stock solutions of different pH were prepared. Seeds were soaked in each concentration for twenty four hours.

Different levels of water stress (-5, -10 and -15 bar) were created by using d-manitol solutions of different osmotic concentrations prepared according to the formula used by Helmerich and Pfeifer (1954). Distilled water used in control treatment. Seeds were soaked in each concentration for twenty four hours According

to Uhvits (1946), Manitol, is non toxic to seeds. Knipe (1973), Bokhari *et al.* (1975), Saxena *et al.* (1998), Sah *et al.* (1989) and Aziz *et al.* (2001) have also used manitol to maintain the desired levels of water stress under laboratory conditions. The daily germination was recorded and was further used for the calculation of other germination related parameters.

Following observations were recorded for measuring germination characteristics and growth of seedlings.

- (i) Number of days taken to initiate germination
- (ii) Number of days taken to complete germination
- (iii) Number of seeds germinated

New germinates were recorded daily starting from the day of germination till the 20th day after sowing to express the germination percentage of seeds.

- (iv) Germination value and mean daily germination
- (v) Vigour index

The observations were recorded as per the procedure adopted for recording observation for first experiment.

(vi) Germination stress index (GSI):

Germination stress index (GSI) = $\frac{\text{Germination of stressed seeds}}{\text{Germination of control seeds}} \times 100$

(a) Seedling growth:

After 20 days of seed sowing root and shoot length of seedlings was measured with the help of scale.

3.3.3: Effect of light and temperature on seed germination:

To study the effect of light on seed germination and seedling growth of *Jatropha curcas* at different levels of light (Red, Far red and Dark) petri dishes were covered with cellophane papers. Thus red light was obtained by wrapping petri dishes with red cellophane paper, while far-red light conditions were obtained by wrapping

petri dishes with blue and red cellophane paper. The dark light condition was obtained by wrapping petri dishes with black carbon paper. Prior to placing of seeds into petri dishes, seeds and filter papers were treated with 2% Bavistin.

To determine the effect of temperature on seed germination of *Jatropha curcas*, three different temperatures (25°C, 30°C and 35°C) were maintained constantly throughout the experimentation period inside of seed germinator. One hundred seventy five seeds each for light and temperature were soaked in distilled water for 24 hours. The seeds were placed in each petri plate lined at seed germinator with two layers of filter paper moistened with distilled water. At the completion of germination all the seedlings were shifted at room temperature and data were taken to compare the growth performance of seedlings in normal room temperature. To avoid the effect of position within the chamber, petri dishes were rearranged at random everyday.

Following observations were recorded for measuring germination characteristics and growth of seedlings with the same methodology as adopted in the above experiment to study the effect of storage and container. Visible radicle growth was used to define germination. Germination was recorded daily and experiment was allowed to proceed for 20 days for seedling growth.

- (i) Number of days taken to initiate germination
- (ii) Number of days taken to complete germination
- (iii) Number of seeds germinated
- (iv) Germination value and mean daily germination
- (v) Vigour index

The observations were recorded as per the procedure adopted for recording observation for second experiment.

(a) Seedling growth:

After 20 days of seed sowing root and shoot length of seedlings was measured with the help of scale.

Part (B) Field experiments

3.3.4: Effect of time and depth of sowing on germination and seedling growth:

To study the effect of time and depth of sowing on germination and seedling growth of *Jatropha curcas*, a field experiment was conducted in three replications. The experiment was designed in Completely Randomized Design for statistical analysis. Freshly collected seeds in each year were stored in gunny bag at room temperature to test germination at the interval of three months (November 2004, March 2005 and July 2005) at different depths (1, 2, 3 and 4cm) and experiment was repeated in next year. Seeds were sown in nursery beds at a distance of 15cm x 5cm. Prior to sowing seeds were treated with Thiram (copper fungicide). Twenty five seeds in each replication for each depth were placed with the help of pointed stick having bowel shaped groove at the tip. After germination seedlings were maintained with great care. Following observations were recorded during this study:

(i) Weather parameters (Temperature and Humidity):

During the course of study temperature and humidity was recorded weakly with the help of Hygro-thermometer and expressed in $^{\circ}\text{C}$ and per cent respectively.

(ii) Number of days taken to initiate germination:

Days taken to initiate germination was counted from the date of seed sowing to the date of emergence of first plumule and expressed in number of days.

(iii) Number of days taken to complete germination:

Days taken to complete germination was counted from the date of seed sowing to the date of last seed germination and expressed in number of days.

(iv) Number of seeds germinated:

New germinates were recorded daily starting from the day of germination till the 20th day after sowing to express the germination percentage of seeds.

(v) Germination percentage:

Germination per cent was calculated as the number of seeds sown and the number of seeds germinated and expressed in percentage. Daily germination was observed. Final germination count was recorded and germination per cent was worked out using following formula.

$$\text{Germination\%} = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds sown}} \times 100$$

(vi) Growth parameters:

(a) Seedling height (cm):

The height of each plant was measured at monthly interval up to 4 months after planting in the field conditions. The height of plants was measured to the nearest centimeter with the help of scale.

(b) Collar diameter (cm):

Collar diameter of the seedlings was recorded at the point of root: shoot union and measured with the help of vernier caliper and expressed in centimeter.

(vii) Total dry weight (g): Three seedlings in each replication in each depth was uprooted and dried in oven at 80⁰ C for 24 hours. After drying, weight was taken by Electronic Weighing Machine in gram.

(viii) Relative Growth Rate (RGR):

Relative growth rate (RGR) of seedlings was recorded on seedling growth. The Relative growth rate (RGR) was calculated by using the following formula as suggested by Gardner *et al.* (1985) and is expressed as $g\ g^{-1}d^{-1}$.

$$RGR = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

Where,

W= plant dry weight

t= time

Suffix 1 and 2 denote to the first and second harvest, respectively.

(ix) Net Assimilatory Rate (NAR):

The photosynthetic efficiency of the plant was measured by calculating Net Assimilation Rate (NAR) as suggested by Gardner *et al.* (1985). The Net Assimilation Rate is defined by Radford (1967) as "an increase of the plant matter per unit of assimilatory area per unit time" and expressed as $mg\ cm^{-2}\ d^{-1}$.

$$NAR = \frac{(W_2 - W_1) (\ln A_2 - \ln A_1)}{(t_2 - t_1) (A_2 - A_1)}$$

Where

W=Plant dry weight

A=Area of the leaf

t= time

Suffix 1 and 2 denote first and second harvest, respectively

(x) Specific leaf weight (SLW):

Specific leaf weight (SLW) is a simple relationship between leaf area and total plant weight. It is calculated by the following formula and expressed in gm^{-2} .

$$\text{SLW} = \frac{\text{LW}}{\text{LA}}$$

Where,

W=Plant dry weight

LA=Area of the leaves

(x) Root-shoot ratio:

The dug out plants were washed with water to remove soil particle. After that the seedlings were cut at collar with a secateur and root and shoot weights were taken separately after drying to constant weight in an oven at 80°C and the ratios of root to shoot were determined. Root to shoot ratio was obtained by dividing dry weight of root by dry weight of shoot and the values were noted down.

(a) Leaf area:

Leaf area was measured at every harvest during study period. Leaves were individually plucked and leaf area was measured with the help of digital leaf area meter and expressed as cm^2 .

(xi) Partitioning of biomass:

After one month of seed sowing to four months at monthly interval, seedlings were uprooted to record biomass. All the three components viz., root, stem and leaves were separately weighed to record fresh and oven dried biomass. Total biomass and its distribution in root and shoot were recorded at each harvesting from three representative harvested seedlings in each replication in each depth. Seedlings were cut into root and shoot to record fresh biomass using electronic balance. Component

wise seedlings were dried at 80°C for 24 hours to record dry biomass and is expressed as gram/plant.

3.3.5: Effect of shade on germination and seedling growth.

For studying the effect of various shade levels on germination and seedling growth of *Jatropha curcas* for obtaining a healthier growing stock, a field experiment with four levels of shade (35% shade, 50% shade, 75% shade and 0% shade as control) were conducted in March, 2005 and March, 2006. The seedlings raised in the poly bags with five replications (25 seeds/ replication) in each shade and experiment was repeated in next year. Netlon shade house having 35%, 50% and 75% shade capacity were used for the maintaining different shade levels. The experiment was planned in completely randomized block design with five replications. Seeds were sown at a distance of 15cm x 5cm. Seedlings were maintained with regular watering and weeding. The seeds started germinating within six days and the data for germination were taken daily till the germination was complete. Following observations were recorded during the investigation period.

- (i) Number of days taken to initiate germination
- (ii) Number of days taken to complete germination
- (iii) Germination percentage

(iv) Growth parameters:

(a) Seedling Height: The height of each plant was measured quarterly up to 4 months days after planting in the field conditions. The height of plants was measured to the nearest centimeter with the help of scale. Height of the seedlings was recorded at monthly interval using scale and expressed in centimeter.

(b) Collar diameter: Collar diameter of the seedlings was recorded at ground level using vernier caliper and expressed in centimeter.

- (v) Total dry weight (g)
- (vi) Relative Growth Rate (RGR)
- (vii) Net Assimilatory rate (NAR)
- (viii) Specific leaf weight (SLW)

The observations were recorded as per the procedure adopted for recording observation for first experiment.

(ix) Root-shoot ratio:

The observations were recorded as per the procedure adopted for recording observation for other nursery experiments. The dug out plants were washed with water to remove soil particle. After that the seedlings were cut at collar with secateurs and root and shoot weights were taken separately after drying to constant weight in an oven at 80⁰c and the ratios of root to shoot were determined. Root to shoot ratio was obtained by dividing dry weight of root by dry weight of shoot and the values were noted down.

(x) Height: Stem dry weight:

Height: Stem dry weight was obtained by dividing the height of the uprooted seedling to dry weight of the seedling stem. Seedlings were dried at 80⁰C for 24 hours to record dry biomass. Height: Stem dry weight is expressed in cm/gram.

3.3.6: Studies on comparison of growth performance of polythene bag and seedbed grown seedlings

To study the effect of polythene bags and nursery bed grown seedling growth of *Jatropha curcas*, a field experiment was conducted in three replications. The experiment was designed in Completely Randomized Block Design for statistical analysis. Freshly collected seeds were sown in polythene bags and nursery beds (March 2005 to March 2006). Twenty five seeds in each replication for polythene bags and nursery beds were placed with the help of pointed stick having bowel

shaped groove at the tip. After germination seedlings were maintained with great care. Polythene bags and nursery beds were filled with different soil mixtures such as- Red soil + F.Y.M. (1:1), Black soil + F.Y.M. (1:1), Red soil + Black soil + FYM (1:1:1) and of Sand + Black soil + F.Y.M. (1:1:1) ratio. The management practices were similar for all the type of seedlings in the nursery and polythene bags. The polythene bags of 15cm x 20cm size and nursery beds of 1x10m size was prepared for raising the seedlings and experiment was repeated in next year. The data were recorded for germination and other parameters from the initiation of germination till the completion.

Following observations were recorded during the course of study:

- (i) Number of days taken to initiate germination
- (ii) Number of days taken to complete germination
- (iii) Germination percentage
- (iv) Growth parameters
 - (a) Seedling Height
 - (b) Collar diameter
- (v) Total dry weight (g)
- (vi) Relative Growth Rate (RGR)
- (vii) Net Assimilatory rate (NAR)
- (viii) Specific leaf weight (SLW)
- (ix) Root-shoot ratio
- (x) Height: Stem dry weight

The observations were recorded as per the procedure adopted for recording observation for second experiment.

3.3.7: Effect of water stress on seedling growth

For studying the effect of various water stress levels on seedling growth of *Jatropha curcas* for obtaining a healthier growing stock, a field experiment with four levels of water stress (Alternate day, After two day, After three day and Daily as a

control) were conducted in March, 2005 and March, 2006. The seedlings were raised in the nursery bed with five replications (25 seeds/ replication) in each stress level. The experiment was planned in Completely Randomized Block Design with five replications. Fresh seeds were collected from uniformly ripe fruits. Uniform potting mixtures was prepared by using combinations of sand, soil and farm yard manure (FYM) in the ratio of 1:1:1. Seeds were placed at a distance of 15cm x 5cm. Seedlings were maintained with daily, alternate day, after two day and after three day watering. The seeds started germinating within six days and the data for germination were taken daily till the germination was complete.

Following observations were recorded during the investigation period.

- (i) Number of days taken to initiate germination
- (ii) Number of days taken to complete germination
- (iii) Germination percentage
- (iv) Growth parameters
 - (a) Seedling Height
 - (b) Collar diameter
- (v) Total dry weight (g)
- (vi) Relative Growth Rate (RGR)
- (vii) Net Assimilatory rate (NAR)
- (viii) Specific leaf weight (SLW)
- (ix) Root-shoot ratio
- (x) Height: Stem dry weight

The observations were recorded as per the procedure adopted for recording observation for second experiment.

Statistical Analysis:

The statistical analysis was carried out to compute the mean and test the significance of differences through CRD observed due to treatments and replications. The standard error and C.D. (critical difference) value at (5%) of germination and

growth parameters were also calculated. The data recorded for different Laboratory and field experiments was statistically analyzed using SPSS Package and tables were prepared using MS Excel 2003 software for depicting the various observations for different treatments and are presented and discussed under Results and discussion chapter.

Results and

Discussion

RESULTS AND DISCUSSION

The studies on seed germination, seedling growth and biomass production in *Jatropha curcas* L. were carried out at the experimental farm of National Research Centre for Agroforestry, Jhansi during 2005-2007. The results obtained on the basis of four related experiments.

The results have been presented experiment wise. Possible explanations have been given duly supported by authentic reports of eminent research workers. The results obtained on the basis of four related experiments have been described in this chapter under the following sub heads:

1. To study the seed longevity and germination under different storage conditions.
2. To standardize time and depth of sowing for optimum seed germination and seedling growth.
3. To study the effect of light, temperature, shade, pH and water stress on seed germination.
4. To compare the growth performance of poly bag and seedbed grown seedlings under different filling mixture.

Laboratory Experiment:

4.1: Effect of storage containers and duration of storage on seed germination

The study was conducted from December, 2005 to December, 2007. Freshly extracted seeds were graded and stored in six types of containers for varying durations. Observations on seed viability as determined by TTZ test, germination percent, days taken to initiate and complete germination, Germination value, Mean Daily Germination and Vigour index of seedlings were recorded and the results have been presented in ensuing pages.

Table 4.1: Viability (%) in *Jatropha curcas* seeds affected by period and type of storage containers

Storage container	2005-06							20006-07						
	P1	P2	P3	P4	P5	P6	p7	P1	P2	P3	P4	P5	P6	P7
Viability of seed														
C1	100.00	100.00	100.00	80.30	71.90	63.80	50.00	100.00	100.00	100.00	82.30	80.10	67.85	59.40
C2	100.00	100.00	100.00	67.20	60.00	58.00	50.00	100.00	100.00	100.00	72.05	63.60	59.00	54.00
C3	100.00	100.00	70.80	62.00	50.00	48.00	45.00	100.00	100.00	66.50	63.90	56.00	49.00	46.50
C4	100.00	100.00	68.80	60.00	49.00	43.90	40.00	100.00	100.00	64.50	62.40	54.50	46.45	41.95
C5	100.00	100.00	63.90	59.90	49.00	43.00	39.20	100.00	100.00	62.00	61.90	54.45	46.00	41.10
C6	100.00	100.00	72.20	65.00	52.90	50.00	48.00	100.00	100.00	68.95	67.10	58.95	51.45	49.00
Mean	100.00	100.00	75.58	65.73	55.47	51.12	45.37	100.00	100.00	75.22	68.28	61.27	53.29	48.66
LSD (0.05)		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS

Contd.

Storage container	Over the year mean								
	P1	P2	P3	P4	P5	P6	P7	LSD	Pooled Mean
Viability of seed									
C1	100.00	100.00	100.00	81.30	76.00	65.83	54.70	NS	82.55
C2	100.00	100.00	100.00	69.63	61.80	58.50	52.00	NS	77.42
C3	100.00	100.00	68.65	62.95	53.00	48.50	45.75	NS	68.41
C4	100.00	100.00	66.65	61.20	51.75	45.18	40.98	NS	66.54
C5	100.00	100.00	62.95	60.90	51.73	44.50	40.15	NS	65.75
C6	100.00	100.00	70.58	66.05	55.93	50.73	48.50	NS	70.25
Mean	100.00	100.00	78.14	67.00	58.37	52.20	47.01		
LSD (0.05)	100.00	NS	NS	NS	NS	NS	NS		

Abbreviations: Containers

- C₁: Air tight plastic jar
- C₂: Plastic bag
- C₃: Paper bag
- C₄: Cloth bag
- C₅: Earthen pot
- C₆: Gunny bag i.e. Control

Period

- P₁: 0 months
- P₂: 2 months
- P₃: 4 months
- P₄: 6 months
- P₅: 8 months
- P₆: 10 months
- P₇: 12 months

4.1.1 Seed viability:

The study for seed viability was conducted at the time of seed collection and continued at the interval of two months afterwards *i.e.* 0 months, 2 month, 4 months, 6 months, 8 months, 10 months and 12 months after collection. Data presented in Table 4.1, showed that hundred percent seed viability was recorded at the time of seed collection. Viability of seed, over the years was recorded maximum (82.55%) under air tight plastic jar container which was higher than all the containers in different months followed by (77.42%) under plastic bag whereas it was minimum (65.75%) under earthen pot storage container. Viability in gunny bag (Control) was 70.25 percent. When we see the performance over the time duration, there was no decrease in seed viability even after four months of storage in air tight plastic jar container and plastic bag (100%) whereas minimum seed viability (62.95%) was recorded under earthen pot container. At the same period gunny bag and paper bag recorded 70.58 and 68.65% viability, respectively. The viability of seed was found maximum (81.30%) in air tight plastic jar container and minimum (60.90%) in earthen pot after six month of storage. The seed viability reduced drastically in paper bag (62.95%) and gunny bag (66.05%) at the end of six months of storage. It is generally reported that seeds of *Jatropha curcas* remain viable for about six months only, but the present studies have shown that after six months of storage plastic containers recorded more than 80% seed viability. The seed viability was maximum in air tight plastic jar container after 10 and 12 months of storage and recorded 65.83 and 54.7%, respectively, followed by plastic bag (58.5 and 52%) and reduction in viability was recorded for earthen pot (44.50 and 40.15%), paper bag (48.50 and 45.75%) and gunny bag (50.73 and 48.50%). Present data revealed that a large percentage of seed remain viable in airtight plastic jar container and polythene bag even after six months and can be used effectively for storage. Present data revealed that viability of seed decreased with increasing time interval irrespective of type of containers. Type of container and storage period showed non- significant variations.

Longevity of seed is a specific characteristic. Pre storage factors affect longevity in storage. Different factors of storage as temperature affect the seed longevity of seeds. In fact, seed deterioration begins at abscission and involves complex physiological changes. Bonner *et al.* (1994) reported that most important factors in storage are seed moisture content and temperature. Orthodox seeds are tolerant to desiccation to low moisture content, while recalcitrant seeds are susceptible to desiccation. Tiwari *et al.* (1994) reported that seeds of *Pongamia pinnata* stored at 5°C or 15°C in sealed container maintaining 74% viability up to one year. Sahai (1999) studies that the effect of storage varies from species to species and variety to variety even under the same storage conditions. Purohit *et al.* (1996) confirmed 100% viability of *Pongamia pinnata* up to 18 months of storage by tetrazolium test. Similarly Rawat *et al.* (2001) reported that the seeds of *A. excelsa* exhibit orthodox storage behaviour as viability period increasing with decrease in storage temperature. Type of container and duration varies with species. Prasad and Kandya (1992) reported that seeds of *Buchanania lanzan* can be stored in glass bottles and air tight polythene bags well up to 2 years. They reported 73% germination in fresh seeds. However, Khullar *et al.* (1991) reported seed viability in the species up to one year. On the contrary, Choubey *et al.* (1997) reported that Chironjee seeds quickly loose viability during storage and observed only 25 % germination after 9 months, when stored in tin container. Although, oily seeds are often difficult to store than starchy seed, but presence of considerable amount of starch in Chironjee helps the species in long storage. It is quite possible that CO₂:O₂ ratio might have changed in containers. It is known fact that reduction in oxygen levels slow down the metabolism and increases longevity. Effect of containers and duration of storage on seed viability and germination has been reported by different workers in number of species (*Buchanania lanzan*, Choubey *et al.*, 1997; *Toona ciliata*, Gurudev and Bhardwaj, 1996; *Acacia nilotica*, Chaturvedi and Das, 2004).

Present study concluded that loose weaving of cotton in gunny bags and paper bags easily allowed the fluctuations in temperature and humidity of external

environments, so they loss the moisture content of seeds even after a short period of storage. Airtight plastic containers and polythene bags can be used effectively for seed storage of the seeds of *Jatropha curcas* for ten to twelve months.

4.1.2: Days taken to initiate and complete germination:

The study for initiation and completion of germination was conducted at the time of seed collection and continued at the interval of two months afterwards *i.e.* 0 months, 2 month, 4 months, 6 months, 8 months, 10 months and 12 months after collection. Effect of storage container and period on the days taken to initiate and complete germination is summarized in Table 4.2 and Table 4.3. Initiation of seed germination over the years was recorded minimum (3.01 days) under air tight plastic jar container followed by 3.46 days under plastic bag whereas it was maximum (4.50 days) under earthen pot storage container. On the other hand initiation in gunny bag (Control) was 3.85 days. It is obvious from the data that days taken to initiate germination were not significantly influenced by type of container used for storage.

When we see the performance over the time duration, after four months of storage minimum initiation of germination was in air tight plastic jar container (2.58 days) followed by plastic bag (3.00 days) whereas maximum initiation of germination (4.00 days) was recorded under earthen pot container. At the same period gunny bag and paper bag recorded 3.38 days. The initiation of seed germination was found minimum (3.13 days) in air tight plastic jar container and maximum (4.43 days) in earthen pot after six months of storage. The initiation of seed germination reduced drastically in paper bag (3.75 days) and gunny bag (3.63 days) at the end of six months of storage. The initiation of seed germination was minimum in air tight plastic jar container after 10 and 12 months of storage and recorded 4.00 and 4.25 days, respectively, followed by plastic bag (4.28 and 4.75 days) and maximum initiation of seed germination was recorded for earthen pot (4.88 and 7 days), paper bag (4.48 and 5.35 days) and gunny bag (4.45 and 5.45 days).

Table 4.2: Effect of storage container and period on initiation of seed germination in *Jatropha curcas*

Storage container	2005-06							20006-07						
	P1	P2	P3	P4	P5	P6	p7	P1	P2	P3	P4	P5	P6	P7
Initiation of germination														
C1	2.25	2.75	3.00	3.50	4.25	4.75	5.00	1.00	1.00	2.15	2.75	3.00	3.25	3.50
C2	2.75	3.00	3.50	4.00	4.75	4.80	5.50	1.75	2.00	2.50	2.95	3.15	3.75	4.00
C3	3.00	3.00	3.75	4.50	4.85	4.95	5.70	2.00	2.75	3.00	3.00	3.50	4.00	5.00
C4	3.15	3.25	4.00	4.75	5.00	5.00	6.00	2.75	3.00	3.20	3.45	3.80	4.50	5.00
C5	3.25	3.50	4.25	4.85	5.15	5.00	6.00	3.00	3.50	3.75	4.00	4.00	4.75	8.00
C6	3.00	3.00	3.75	4.25	4.80	4.95	5.90	2.50	2.50	3.00	3.00	4.25	3.95	5.00
Mean	2.90	3.08	3.71	4.31	4.80	4.91	5.68	2.17	2.46	2.93	3.19	3.62	4.03	5.08
LSD (0.05)		NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS

Contd.

Storage container	Over the year mean								
	P1	P2	P3	P4	P5	P6	P7	LSD	Pooled Mean
Initiation of germination									
C1	1.63	1.88	2.58	3.13	3.63	4.00	4.25	NS	3.01
C2	2.25	2.50	3.00	3.48	3.95	4.28	4.75	NS	3.46
C3	2.50	2.88	3.38	3.75	4.18	4.48	5.35	NS	3.79
C4	2.95	3.125	3.60	4.10	4.40	4.75	5.50	NS	4.06
C5	3.13	3.50	4.00	4.43	4.58	4.88	7.00	NS	4.50
C6	2.75	2.75	3.38	3.63	4.53	4.45	5.45	NS	3.85
Mean	2.53	2.77	3.32	3.75	4.21	4.47	5.38		
LSD (0.05)		NS	NS	NS	NS	NS	NS		

Days to complete germination followed similar trend as that to initiate germination, with respect to duration of storage. Completion of seed germination over the years was recorded minimum (5.78 days) under air tight plastic jar container followed by (6.45 days) under plastic bag whereas it was maximum (7.77 days) under earthen pot storage container (Table 4.3). On the other hand completion in gunny bag (Control) was 6.78 days. It is obvious from the data that days taken to complete germination were not significantly influenced by type of container used for storage.

When we see the performance over the time duration, after four months of storage completion of germination was minimum in air tight plastic jar container (5.13 days) followed by plastic bag (5.63 days) whereas completion of germination was maximum (7.25 days) under earthen pot container. At the same period gunny bag and paper bag recorded 5.95 and 6.13 days, respectively. The completion of seed germination was found minimum (6.13 days) in air tight plastic jar container followed by plastic bag (6.63 days), gunny bag (6.85 days) and maximum (7.63 days) in earthen pot after six month of storage. The completion of seed germination was minimum in air tight plastic jar container after 8, 10 and 12 months of storage and recorded 6.33, 6.63 and 7.50 days, respectively, followed by plastic bag (7.23, 7.50 and 8.63 days) and completion of seed germination was recorded maximum for earthen pot (8.88, 9.50 and 10.38 days), paper bag (8.63 and 9.45 days) and gunny bag (7.50, 8 and 9 days).

The data on days taken to initiate and complete germination revealed that type of containers and time of storage period did not significantly influence days taken to initiate and complete germination.

Table 4.3: Effect of storage container and period on completion of seed germination in *Jatropha curcas*

Storage container	2005-06							2006-07						
	P1	P2	P3	P4	P5	P6	p7	P1	P2	P3	P4	P5	P6	P7
Completion of germination														
C1	4.00	4.50	5.00	6.25	6.50	7.00	8.00	4.00	5.00	5.25	6.00	6.15	6.25	7.00
C2	4.00	5.00	5.75	6.50	7.50	8.00	9.75	5.00	5.15	5.50	6.75	6.95	7.00	7.50
C3	5.00	5.00	6.25	7.00	9.00	9.50	10.15	5.00	5.50	6.00	7.00	7.50	7.75	8.75
C4	5.00	5.15	6.50	7.15	9.25	10.00	10.50	5.00	6.00	7.00	7.25	8.00	8.15	9.00
C5	5.00	5.25	7.00	7.25	9.50	10.25	10.75	5.00	6.25	7.50	8.00	8.25	8.75	10.00
C6	5.00	5.00	6.15	6.75	8.00	8.50	10.00	5.00	5.25	5.75	6.95	7.00	7.50	8.00
Mean	4.67	4.98	6.11	6.82	8.29	8.88	9.86	4.83	5.53	6.17	6.99	7.31	7.57	8.38
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.3 Contd.

Storage container	Over the year mean								
	P1	P2	P3	P4	P5	P6	P7	LSD	Pooled Mean
Completion of germination									
C1	4.00	4.75	5.13	6.13	6.33	6.63	7.50	NS	5.78
C2	4.50	5.08	5.63	6.63	7.23	7.50	8.63	NS	6.45
C3	5.00	5.25	6.13	7.00	8.25	8.63	9.45	NS	7.10
C4	5.00	5.58	6.75	7.20	8.63	9.08	9.75	NS	7.43
C5	5.00	5.75	7.25	7.63	8.88	9.50	10.38	NS	7.77
C6	5.00	5.13	5.95	6.85	7.50	8.00	9.00	NS	6.78
Mean	4.75	5.25	6.14	6.90	7.80	8.22	9.12		
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS		

High aridity and low pace of biochemical changes in seed, might have delayed initiation and completion of germination. Puróhit and Jammaluddin (2003) reported that seeds stored in plastic jars and poly bags gave the better germination during whole storage period while it was very poor in seed stored in jute and cloth bags.

Prasad and Kandya (1992) reported that seeds of *Buchanania lanzan* take 3-12 days to initiate and complete germination. Further, they reported that days taken to initiate and complete germination varies from days to month in different species.

4.1.3: Germination per cent, Germination value and Mean daily germination:

Data on Germination per cent, Germination value and Mean Daily Germination as influenced by storage duration and type of containers have been presented in Table 4.4, 4.5 and 4.6.

4.1.3.1: Germination per cent:

The study for Germination percent was conducted at the time of seed collection and continued at the interval of two months afterwards i.e. 0 months, 2 month, 4 months, 6 months, 8 months, 10 months and 12 months after collection. Data presented in Table 4.4, showed that 96.8 percent seed germination was recorded at the time of seed collection. Germination percent, over the years was recorded

maximum (72.20%) under air tight plastic jar container followed by 69.71 percent under plastic bag whereas it was minimum (50.90%) under earthen pot storage container. Germination percentage in gunny bag (Control) was 55.65 percent. When we see the performance over the time duration, after four months of storage in air tight plastic jar container 90.30 germination percent was recorded followed by plastic bag (87.0%) whereas minimum germination percentage (50.25%) was recorded under earthen pot container. Air tight plastic jar, plastic bag and gunny bag are significantly higher than other storage containers. At the same period gunny bag and paper bag recorded 70.58 and 53.85% germination percentage, respectively. The germination percentage of seed was found maximum (69.50%) in air tight plastic jar container and minimum (39.30%) in earthen pot after six months of storage. Air tight plastic jar and plastic bag are significantly higher than other storage containers. The germination percentage reduced drastically in paper bag (44.50%) and gunny bag (46.50%) at the end of six months of storage. It is generally reported that seeds of *Jatropha curcas* remain viable for about six months only, but the present studies have shown that after six months of storage plastic containers recorded more than 70% germination percentage. The germination percentage was maximum in air tight plastic jar container after 8, 10 and 12 months of storage and recorded 54.15, 51.55 and 47.50%, respectively, followed by plastic bag (50, 50.15 and 45%) and reduction in germination percentage was recorded for earthen pot (31.50, 29.45 and 27.50%), paper bag (36.50, 30.50 and 30%) and gunny bag (31.60, 30 and 28.50%). Air tight plastic jar and plastic bag are significantly higher than other storage containers.

Present data revealed that a large percentage of seed remain viable in airtight plastic container and poly bag even after six months and can be used effectively for storage.

Table 4.4: Effect of storage container and period on germination percentage in *Jatropha curcas*

Storage container	2005-06							2006-07						
	P1	P2	P3	P4	P5	P6	P7	P1	P2	P3	P4	P5	P6	P7
Germination percentage														
1	97.10	96.70	90.60	68.80	53.30	52.10	45.00	96.50	94.50	90.00	70.20	55.00	51.00	50.00
2	97.10	94.00	85.50	60.00	50.00	51.00	40.00	96.50	94.00	88.50	70.00	50.00	49.30	50.00
3	97.10	90.00	52.20	40.00	33.00	31.00	30.00	96.50	92.00	55.50	49.00	40.00	30.00	30.00
4	97.10	80.00	51.20	40.00	32.60	30.00	29.60	96.50	87.00	53.50	50.00	40.00	32.00	30.00
5	97.10	78.00	50.00	38.60	31.00	28.90	27.00	96.50	85.00	50.50	40.00	32.00	30.00	28.00
6	97.10	92.00	70.30	44.00	31.20	30.00	28.00	96.50	91.00	70.95	49.00	32.00	30.00	29.00
Mean	97.10	88.45	68.47	48.57	38.52	37.17	33.27	96.50	90.58	69.33	54.70	41.50	37.05	36.17
SD (0.05)		7.80	6.20	5.50	6.00	8.00	7.50		8.00	9.50	6.70	8.00	7.50	8.50

Contd.

Storage container	Over the year mean								
	P1	P2	P3	P4	P5	P6	P7	LSD	Pooled Mean
Germination percentage									
C1	96.80	95.60	90.30	69.50	54.15	51.55	47.50	NS	72.20
C2	96.80	94.00	87.00	65.00	50.00	50.15	45.00	NS	69.71
C3	96.80	91.00	53.85	44.50	36.50	30.50	30.00	NS	54.74
C4	96.80	83.50	52.35	45.00	36.30	31.00	29.80	NS	53.54
C5	96.80	81.50	50.25	39.30	31.50	29.45	27.50	NS	50.90
C6	96.80	91.50	70.58	46.50	31.60	30.00	28.50	NS	55.65
Mean	96.80	89.52	68.40	51.63	40.01	37.11	34.72		
LSD (0.05)		10.00	8.90	7.60	5.00	8.00	7.60		

Present data revealed that germination percentage of seed decreased with increasing time interval irrespective of type of containers. Bhardwaj *et al.* (2001) observed 62% germination after four months of storage when seed stored in polythene bag. Pushkar and Babeley (2001) concluded that the seeds stored in sealed containers (glass bottle) at room temperature gave good germination than other containers and conditions.

4.1.3.2: Germination Value (GV):

The study for Germination value was conducted at the time of seed collection and continued at the interval of two months afterwards *i.e.* 0 months, 2 month, 4 months, 6 months, 8 months, 10 months and 12 months after collection. Data presented in Table 4.5, showed that 61.14 germination value was recorded at the time of seed collection. It is evident from the data that germination value, over the years was recorded maximum (49.78) under air tight plastic jar container which was higher than all the containers in different months followed by 40.99 under plastic bag whereas it was minimum (12.31) under earthen pot storage container. Germination value in gunny bag (Control) was 15.86. When we see the performance over the time duration, after four months of storage in air tight plastic jar container 70.48 germination value was recorded followed by plastic bag (46.40) whereas minimum germination value (20.79) was recorded under earthen pot container. Air tight plastic jar and plastic bag are significantly higher than other storage containers. At the same period gunny bag and paper bag recorded 21.72 and 26.38 germination value, respectively.

The germination value of seed was found maximum (45.39) in air tight plastic jar container and minimum (10.31) in earthen pot after six month of storage. Air tight plastic jar and plastic bag are significantly higher than other storage containers. The germination value reduced drastically in paper bag (19.07) and gunny bag (13.50) at the end of six months of storage. The present studies have shown that after six months of storage plastic containers recorded more than 22.43 germination value.

The germination value was maximum in air tight plastic jar container after 8, 10 and 12 months of storage and recorded 34.25, 23.34 and 12.67, respectively, followed by plastic bag (20.76, 20.06 and 10.43) and reduction in germination value was recorded for earthen pot (10.65, 6.20 and 2.65), paper bag (13.27, 7.07 and 3.17) and gunny bag (8.43, 7.50 and 3.17). Air tight plastic jar and plastic bag are significantly higher than other storage containers. Present data revealed that germination value of seed decreased with increasing time interval irrespective of type

of containers. Maithani *et al.* (1989) reported significant impact of different storage containers on seed germination and observed that the need of proper aeration during the storage period and the negative impact of sealed container (polythene bags and plastic containers) on seed germination due to lack of aeration and storage of high moisture seeds in sealed containers. Similar trend of germination percentage was observed for germination value and maximum GV was observed for seed stored in airtight containers and polythene bags.

Table 4.5: Effect of storage container and period on germination value in *Jatropha curcas*

Storage container	2005-06							20006-07						
	P1	P2	P3	P4	P5	P6	p7	P1	P2	P3	P4	P5	P6	P7
Germination value														
C1	97.10	85.96	72.48	44.03	32.80	22.33	11.25	96.50	68.57	46.80	35.77	29.77	24.48	19.80
C2	97.10	56.40	44.61	36.92	20.00	19.13	8.21	77.20	48.27	41.48	21.58	28.82	21.13	21.60
C3	58.26	54.00	25.06	17.14	11.00	6.53	2.96	57.90	27.75	21.00	16.00	38.34	7.74	11.63
C4	58.26	46.60	23.63	16.78	10.57	6.00	2.82	57.90	22.93	20.69	15.00	8.91	7.85	4.20
C5	38.84	44.57	21.43	10.65	9.79	5.64	2.51	38.60	20.20	10.00	11.64	7.74	6.86	4.11
C6	38.84	36.80	20.59	13.04	7.80	7.06	2.80	38.60	22.94	14.10	9.14	33.55	8.00	6.13
Mean	62.42	53.25	32.15	21.38	13.94	9.77	4.50	59.90	32.75	23.47	17.04	24.52	11.43	
LSD (0.05)		12.50	11.60	10.60	11.00	9.80	9.00		13.00	12.00	11.80	11.80	8.90	9.80

Contd.

Storage container	Over the year mean								
	P1	P2	P3	P4	P5	P6	P7	LSD	Pooled Mean
Germination value									
C1	96.80	80.51	70.48	45.39	34.25	23.34	12.67	NS	49.78
C2	86.04	55.57	46.40	39.25	20.76	20.06	10.43	NS	40.99
C3	58.08	52.00	26.38	19.07	13.27	7.07	3.17	NS	21.38
C4	58.08	44.93	23.27	18.75	12.63	6.83	3.06	NS	20.27
C5	38.72	42.52	20.79	10.31	10.65	6.20	2.65	NS	12.31
C6	38.72	35.71	21.72	13.58	8.43	7.50	3.17	NS	15.86
Mean	61.14	51.11	32.45	22.43	15.39	10.53	5.08	NS	
LSD (0.05)		14.50	13.20	12.80	9.20	10.00	7.00		

of containers. Maithani *et al.* (1989) reported significant impact of different storage containers on seed germination and observed that the need of proper aeration during the storage period and the negative impact of sealed container (polythene bags and plastic containers) on seed germination due to lack of aeration and storage of high moisture seeds in sealed containers. Similar trend of germination percentage was observed for germination value and maximum GV was observed for seed stored in airtight containers and polythene bags.

Table 4.5: Effect of storage container and period on germination value in *Jatropha curcas*

Storage container	2005-06							2006-07						
	P1	P2	P3	P4	P5	P6	P7	P1	P2	P3	P4	P5	P6	P7
Germination value														
C1	97.10	85.96	72.48	44.03	32.80	22.33	11.25	96.50	68.57	46.80	35.77	29.77	24.48	19.80
C2	97.10	56.40	44.61	36.92	20.00	19.13	8.21	77.20	48.27	41.48	21.58	28.82	21.13	21.60
C3	58.26	54.00	25.06	17.14	11.00	6.53	2.96	57.90	27.75	21.00	16.00	38.34	7.74	11.63
C4	58.26	46.60	23.63	16.78	10.57	6.00	2.82	57.90	22.93	20.69	15.00	8.91	7.85	4.20
C5	38.84	44.57	21.43	10.65	9.79	5.64	2.51	38.60	20.20	10.00	11.64	7.74	6.86	4.11
C6	38.84	36.80	20.59	13.04	7.80	7.06	2.80	38.60	22.94	14.10	9.14	33.55	8.00	6.13
Mean	62.42	53.25	32.15	21.38	13.94	9.77	4.50	59.90	32.75	23.47	17.04	24.52	11.43	
LSD (0.05)		12.50	11.60	10.60	11.00	9.80	9.00		13.00	12.00	11.80	11.80	8.90	9.80

Contd.

Storage container	Over the year mean								
	P1	P2	P3	P4	P5	P6	P7	LSD	Pooled Mean
Germination value									
C1	96.80	80.51	70.48	45.39	34.25	23.34	12.67	NS	49.78
C2	86.04	55.57	46.40	39.25	20.76	20.06	10.43	NS	40.99
C3	58.08	52.00	26.38	19.07	13.27	7.07	3.17	NS	21.38
C4	58.08	44.93	23.27	18.75	12.63	6.83	3.06	NS	20.27
C5	38.72	42.52	20.79	10.31	10.65	6.20	2.65	NS	12.31
C6	38.72	35.71	21.72	13.58	8.43	7.50	3.17	NS	15.86
Mean	61.14	51.11	32.45	22.43	15.39	10.53	5.08	NS	
LSD (0.05)		14.50	13.20	12.80	9.20	10.00	7.00		

4.1.3.3: Mean daily germination (MDG):

The study for Mean daily germination was conducted at the time of seed collection and continued at the interval of two months afterwards *i.e.* 0 months, 2 month, 4 months, 6 months, 8 months, 10 months and 12 months after collection. Data presented in Table 4.6, showed that 20.38 mean daily germination was recorded at the time of seed collection. It is evident from the data that mean daily germination over the years was recorded maximum (12.49) under air tight plastic jar container followed by 10.80 under plastic bag whereas it was minimum (6.55) under earthen pot storage container. Mean daily germination in gunny bag (Control) was 8.21.

When we see the performance over the time duration, after four months of storage in air tight plastic jar container, mean daily germination was 15.69 followed by plastic bag (13.90) whereas minimum mean daily germination (8.15) was recorded under earthen pot container. Air tight plastic jar and plastic bag are significantly higher than other storage containers. At the same period gunny bag and paper bag recorded 12.19 and 10.59 mean daily germination, respectively. Mean daily germination of seed was found maximum (11.35) in air tight plastic jar container and minimum (5.15) in earthen pot after six month of storage. Mean daily germination reduced drastically in paper bag (6.36) and gunny bag (6.79) at the end of six months of storage. Air tight plastic jar and plastic bag are significantly higher than other storage containers. It is generally reported that seeds of *Jatropha curcas* remain viable for about six months only, but the present studies have shown that after six months of storage plastic containers recorded more than 7.48 mean daily germination.

Mean daily germination was maximum in air tight plastic jar container after 8, 10 and 12 months of storage and recorded 8.56, 7.78 and 6.33, respectively, followed by plastic bag (6.92, 6.69 and 5.22) and reduction in mean daily germination was recorded for earthen pot (3.55, 3.10 and 2.65), paper bag (4.42, 3.54 and 3.17) and gunny bag (4.21, 3.75 and 3.17). Air tight plastic jar and plastic bag are significantly higher than other storage containers. Present data revealed that mean daily

germination of seed decreased with increasing time interval irrespective of type of containers.

It is evident from the data that MDG was not significantly influenced by the type of containers. However, storage duration showed significant effect on MDG. MDG decreased with increase in storage duration, irrespective of container.

Table 4.6: Effect of storage container and period on Mean daily germination in *Jatropha curcas*

Storage container	2005-06							2006-07						
	P1	P2	P3	P4	P5	P6	p7	P1	P2	P3	P4	P5	P6	P7
Mean daily germination														
C1	24.28	21.49	18.12	11.01	8.20	7.44	5.63	24.13	18.90	17.14	11.70	8.94	8.16	7.14
C2	24.28	18.80	14.87	9.23	6.67	6.38	4.10	19.30	18.25	16.09	10.37	7.19	7.04	6.67
C3	19.42	18.00	8.35	5.71	3.67	3.26	2.96	19.30	16.73	9.25	7.00	5.33	3.87	3.43
C4	19.42	15.53	7.88	5.59	3.52	3.00	2.82	19.30	14.50	7.64	6.90	5.00	3.93	3.33
C5	19.42	14.86	7.14	5.32	3.26	2.82	2.51	19.30	13.60	6.73	5.00	3.88	3.43	2.80
C6	19.42	18.40	10.29	6.52	3.90	3.53	2.80	19.30	17.33	11.47	7.05	4.57	4.00	3.63
Mean	20.81	17.75	10.72	7.13	4.65	4.19	3.37	19.97	16.40	10.92	7.82	5.68	4.90	4.32
LSD (0.05)		3.20	5.00	4.30	3.10	3.00	2.80		4.30	4.10	3.50	3.10	2.80	2.90

Contd.

Storage container	Over the year mean								
	P1	P2	P3	P4	P5	P6	P7	LSD	Pooled Mean
Mean daily germination									
C1	24.20	17.62	15.69	11.35	8.56	7.78	6.33	NS	12.49
C2	21.51	15.47	13.90	9.81	6.92	6.69	5.22	NS	10.80
C3	19.36	8.79	10.59	6.36	4.42	3.54	3.17	NS	7.71
C4	19.36	7.76	8.89	6.25	4.21	3.42	3.06	NS	7.21
C5	19.36	6.93	8.15	5.15	3.55	3.10	2.65	NS	6.55
C6	19.36	10.86	12.19	6.79	4.21	3.75	3.17	NS	8.21
Mean	20.38	10.82	11.57	7.48	5.13	4.51	3.81	NS	
LSD (0.05)		5.50	4.30	4.00	3.90	4.00	2.20		

Mean daily germination showed non-significant variations with type of containers, which supports our findings of germination percent and germination value in this experiment. Significant effect of duration on MDG is in accordance with above two parameters, which may be attributed to post ripening storage requirement of *Jatropha curcas* seeds. Sharma *et al.* (2004) reported 50 to 60% seed germination in *Hippophae tibetana* Schelter, when stored in plastic container for one year. Rao *et al.* (1984) reported viability of *Populus ciliata* seeds only up to 12 days, when freshly collected seeds were stored in the polythene bags under laboratory conditions.

4.1.3.4: Vigour index (VI):

The study for vigour index was conducted at the time of seed collection and continued at the interval of two months afterwards *i.e.* 0 months, 2 month, 4 months, 6 months, 8 months, 10 months and 12 months after collection. Data presented in Table 4.7, showed that 1840.53 vigour index was recorded at the time of seed collection. It is evident from the data that vigour index, over the years was recorded maximum (1514.48) under air tight plastic jar container followed by 1376.54 under plastic bag whereas it was minimum (850) under earthen pot storage container.

Vigour index in gunny bag (Control) was 1112.76. When we see the performance over the time duration, after four months of storage in air tight plastic jar container, vigour index was 1737.82 followed by plastic bag (1609.50) whereas minimum vigour index (824.10) was recorded under earthen pot container. At the same period gunny bag and paper bag recorded 1185.87 and 955.84 vigour index, respectively. Air tight plastic jar and plastic bag are significantly higher than other storage containers. Vigour index of seed was found maximum (1285.75) in air tight plastic jar container and minimum (613.08) in earthen pot after six months of storage. Vigour index reduced drastically in paper bag (745.38) and gunny bag (797.48) at the end of six months of storage. Air tight plastic jar and plastic bag are significantly higher than other storage containers. Vigour index was maximum in air tight plastic jar container after 8, 10 and 12 months of storage and recorded 963.87, 850.58 and

736.25, respectively, followed by plastic bag (862.50, 809.92 and 702) and reduction in vigour index was recorded for earthen pot (480.38, 403.47 and 346.50), paper bag (591.30, 468.18 and 439.50) and gunny bag (518.24, 468.0 and 432.49). Air tight plastic jar and plastic bag are significantly higher than other storage containers.

Present data revealed that vigour index of seed decreased with increasing time interval irrespective of type of containers.

Table 4.7: Effect of storage container and period on vigour index in *Jatropha curcas*

Storage container	2005-06							2006-07						
	P1	P2	P3	P4	P5	P6	P7	P1	P2	P3	P4	P5	P6	P7
Vigour index														
C1	1771.38	1755.11	1602.71	1169.60	884.78	833.60	675.00	2123.00	1984.50	1872.00	1404.00	1045.00	867.00	800.00
C2	1747.80	1654.40	1453.50	990.00	825.00	805.80	616.00	2098.88	1955.20	1770.00	1330.00	900.00	813.45	790.00
C3	1689.54	1539.00	835.20	600.00	488.40	455.70	438.00	2026.50	1821.60	1082.25	906.50	704.00	480.00	441.00
C4	1553.60	1248.00	793.60	600.00	472.70	390.00	378.88	1930.00	1653.00	963.00	890.00	680.00	480.00	390.00
C5	1514.76	1170.00	750.00	524.96	418.50	369.92	334.80	1785.25	1513.00	898.90	704.00	544.00	438.00	358.40
C6	1754.74	1646.80	1063.44	682.00	468.00	450.00	429.80	2084.40	1820.00	1312.41	921.20	569.60	486.00	435.00
Mean	1671.97	1494.07	1069.18	749.60	583.58	540.82	474.37	2008.00	1787.51	1301.62	1018.33	735.93	588.48	526.27
LSD (0.05)		312.50	350.80	422.10	250.80	365.00	288.90		333.30	289.00	255.40	156.80	189.60	125.50

Contd.

Storage container	Over the year mean								
	P1	P2	P3	P4	P5	P6	P7	LSD	Pooled Mean
Vigour index									
C1	1947.75	1871.37	1737.82	1285.75	963.87	850.58	736.25	NS	1514.48
C2	1923.90	1804.80	1609.50	1153.75	862.50	809.92	702.00	NS	1376.54
C3	1858.56	1678.95	955.84	745.38	591.30	468.18	439.50	NS	1016.86
C4	1742.40	1444.55	876.86	738.00	571.73	434.00	384.42	NS	953.42
C5	1650.44	1336.60	824.10	613.08	480.38	403.47	346.50	NS	850.00
C6	1920.10	1733.93	1185.87	797.48	518.24	468.00	432.49	NS	1112.76
Mean	1840.53	1639.27	1184.00	879.00	657.83	564.69	500.11	NS	
LSD (0.05)		456.90	412.23	350.50	256.36	288.80	212.20		

4.2: Effect of pH and water stress on seed germination:

The development of embryo into a fully developed plant involves a sequence of steps, beginning with the uptake of water, leading to the rupture of the seed coat and emergence of radical and plumule. A number of chemical reactions take place in each steps and success of these reactions is dependent upon the proper functioning of the permeable membrane surrounding the different organelles within the cellular structure of the seed. A number of external and internal factors such as pH, and water stress affect the seed germination of *Jatropha curcas*.

The study was conducted during 2005 and 2006. Freshly extracted seeds were subjected to various pH levels (5 to 9) and water stress (-5, -10, -15 bar) at constant humidity for germination. Observations on germination percentage, germination value, mean daily germination and number of days taken to initiate and complete germination were recorded during the course of investigation. Seedling growth in terms of radicle and plumule length was also recorded at termination of study *i.e.* 15 days after seed sowing. The results have been presented and discussed in light of available data and inferences have been drawn accordingly.

4.2.1: Effect of pH:

4.2.1.1: Days taken to initiate and complete germination and germination Percentage:

Effect of pH on days taken to initiate and complete germination are presented in Table 4.8. The data revealed that the time taken for germination was affected by the level of pH. Initiation of germination was minimum days under the treatment pH 7 (1.14 days) whereas it was maximum under the treatment pH 9 (2.29 days). Days taken to initiate germination recorded for pH 5 and pH 6 were statistically at par with each other. Similarly, days taken to complete germination was minimum at pH7 (5.57 days) and maximum (10.50 days) at pH 9, which was significantly higher than all the pH except for pH 6.

It was obvious from the result that pH level significantly affect the days taken to initiate and complete germination. Higher pH level (pH 9) took more days to initiate and complete germination. It may be attributed to the fact that the species is not suitable for very high pH level.

It was evident from the data that germination percentage was recorded maximum (65.72) at pH 7. As the pH level was increased or decreased, seed germination was decreased. Data reveals that, seed germination was minimum (34.29%) at pH 9 and followed by pH 6 (41.43 %) and pH 5 (48.57 %). Table (4.3)

Garg and Khanduja (1979) reported the success of *Pongamia* on soil with pH 9. Srinivasu and Toky (1996) reported that the seed germination decreased and delayed with increasing alkalinities. Generally, severe acidic as well as strong basic conditions of the medium inhibited seed germination. Reduction in pH resulted in more number of days to initiate and complete germination. This may be attributed to increased hydrogen ion concentration in the germination media. Mandal and Handoo (1998) reported that germination of subabool seeds was delayed with the increasing in salinity level, while working on seed germination of *Acacia nilotica*, *Albizia lebbeck*, *Pithecellobium dulce* and *Prosopis juliflora* under alkalinities of sodium carbonate and sodium bicarbonate for 30 days in solution and soil culture. The adverse effect of low pH and high Al in *Cryptomeria japonica* has been reported by Hirano and Hijee, (1998). Finding of present study were in conformity with above study, which showed that days taken to initiate and complete germination increased with increase and decrease in pH level. It can be concluded from the study that pH 7 was suitable for seed germination. This indicated that species required neutral or slightly acidic pH media for optimum germination. The problems of seed germination at specified pH levels have been discussed by Redmann and Abougudendia, (1979).

ble 4.8: Effect of different levels of pH on, initiation and completion of germination and germination percentage in *Jatropha curcas*

pH	Parameters								
	Initiation of germination (days)			Completion of germination (days)			Germination (%)		
	2005	2006	Pooled mean	2005	2006	Pooled mean	2005	2006	Pooled mean
5	1.43	2.14	1.79	6.57	9.86	8.22	51.43	45.71	48.57
6	1.29	2.29	1.79	9.86	9.14	9.50	40.00	42.86	41.43
7	1.14	1.14	1.14	5.43	5.71	5.57	74.29	57.14	65.72
8	1.29	1.43	1.36	6.00	6.29	6.15	62.86	47.14	55.00
9	2.43	2.14	2.29	10.71	10.29	10.50	34.29	34.29	34.29
LSD (0.05)	NS	NS	0.89	0.99	0.87	1.06	NS	NS	16.04

4.2.1.2: Germination parameters:

Available literature reveals that in some tree species, severe acidic as well as strong basic conditions of the medium inhibits seed germination. It was evident from the data presented in Table 4.4, that pH level significantly influenced seed germination of the species.

Mean daily germination (Table 4.9) was recorded maximum (11.85) in pH 7 which was significantly higher than that of other treatments except for pH 8. MDG was recorded minimum in pH 9 (3.27), which was statistically at par with pH 6 (4.38) and pH 5 (6.24). Germination value (Table 4.9) was also significantly influenced by pH level. At pH 7 maximum germination value (23.88) was recorded, which was very high than that of other treatments. With the reduction in pH, GV was recorded 9.06 (pH 6) and 10.40 (pH 5), respectively. At pH 8, germination value was observed to be 15.33. Minimum germination value was recorded at pH 9 (3.54).

Vigour index (Table 4.9) was significantly influenced by pH level. At pH 7 maximum vigour index (1282.10) was recorded, which was significantly higher than that of other treatments. With the reduction in pH, vigour index was recorded 834.29 at pH 6 and 747.43 at pH 5. At pH 8, vigour index was observed to be 1055. Minimum vigour index was recorded at pH9 (562.72). The similar trend was recorded

for germination stress index and recorded maximum germination index (100.00) at pH 7 which was amply higher than other treatments.

Table 4.9: Effect of different levels of pH on Mean daily germination, Germination value, Vigour index and Germination stress index in *Jatropha curcas*

pH	Parameters											
	Mean daily germination			Germination Value			Vigour index			Germination stress index		
	2005	2006	Pooled mean	2005	2006	Pooled mean	2005	2006	Pooled mean	2005	2006	Pooled mean
5	7.83	4.64	6.24	9.63	11.17	10.40	742.86	751.99	747.43	56.50	101.69	79.05
6	4.06	4.69	4.38	10.97	7.14	9.06	1034.29	634.29	834.29	56.50	30.00	43.25
7	13.68	10.01	11.85	18.98	28.77	23.88	1465.71	1098.57	1282.10	100.00	100.00	100.00
8	10.48	7.49	8.99	15.48	15.17	15.33	1212.86	897.14	1055.00	100.00	56.50	78.25
9	3.20	3.33	3.27	3.57	3.51	3.54	580.57	544.86	562.72	33.89	45.20	39.55
LSD (0.05)	1.37	0.89	2.94	NS	NS	NS	146.70	90.53	213.40	NS	NS	NS

Germination stress index (Table 4.9) at different pH levels were 79.05 at pH 5, 43.25 at pH 6, 78.25 at pH 8 and 39.55 at pH 9. Present data revealed that among all the five treatments, the control treatment *i.e.* pH 7 was excellent for all the germination related parameters. Germination parameter gradually increased from pH 5 to pH 7. Again in basic medium there was decline at pH 8. From this experiment it was concluded that *Jatropha curcas* can tolerate a wide range of pH and can grow adequately from pH 5 to 8.

The present investigation concludes that all the germination parameters were maximum at pH 7 and gradually decreased with increase as well as decrease in pH. Mishra *et al.* (1988) recorded 33-63% germination in *Pongamia pinnata* at 7, 9, 10 and 11 pH level. Garg and Khanduja (1979) reported the success of *P. pinnata* on soil with pH 9. Naidu *et al.* (1999) reported that *P. pinnata* can grow well in alkali soils having the values of pH 9.4. Masilamani *et al.* (2002) observed significant difference among different treatments of pH (8.1, 9.0, 10.2 and 10.5) for all the parameters of germination.

Singh (1992) observed that under saline conditions *P. pinnata* failed at ECE 32.5dsm-1. Similar trend of germination percentage were recorded for mean daily germination, germination value and germination stress index. Findings of present study were in conformity with above study, which showed that low pH level not suitable for the species. Ahlawat and Dagar (1980) reported that in *Bidens biternata* there was complete inhibition of germination at pH 2.5 but the germination percentage gradually increased from pH 3 to pH 7. Again in the basic medium there was decline and at pH 9, percentage of germination was again zero. Present study also supports the findings of Sah *et al.* (1989); they reported that the rate of germination for *Pinus roxberghii*, *P. wallichiana*, *P. patula* and *P. greggii* was higher at pH 5, 6 and 7 as compared to pH 4 or 8.

Soil reactions (pH) of germinating media influences effect seed germination. With the increase in pH, germination is adversely effected on account of high salt concentration. Excess of sodium, which is mainly responsible for high pH causes exo-osmosis and thereby adversely affects seed germination (Singh, 1989). Further, excess of chloride in soils causes burning of germinating seeds, thus hampers germination (Yadav and Singh, 1970).

In the present study, effect of pH was quite visible. High pH delayed emergence and completion of germination, as well. This is obviously due to higher salt concentration in the growing media. Minimum days taken to initiate and complete germination were recorded at 6 pH.

However, Reduction in pH resulted in more number of days taken to initiate and complete germination. This may be attributed to increased Hydrogen ion concentration in the germinating media.

Effect of low pH on root growth and development in *Cryptomeria japonica* is reported by Hirano and Hijee, (1998). While working on seed germination and seedling growth of 9 species, Tomar and Yadav (1980) reported that with the increasing level of salinity in irrigation water percent seed germination, shoot growth and root length of all species reduced and mortality increased. All species were found

sensitive to saline water at the early stages of germination. Similarly, Mandal and Handoo (1998) reported decline and delay of germination with the increasing level of salinity. They also reported decrease in germination value, vigour index and root shoot ratio with the increase in salinity. Reduction in seed germination and seedling growth of *Acacia nilotica*, *Albizia lebbeck*, *Pithecelobium dulce* and *Prosopis juliflora* under the alkalinities of sodium carbonate and bicarbonate have been reported by Srinivasu and Toky, (1996).

Tewari *et al.* (2000) reported almost three times root than shoot length in *Jatropha curcas*. Visual symptoms indicated adverse effect of high pH on *Jatropha curcas*. Burning and necrosis of radicle at pH 8 may be attributed to presence of high concentration of injurious salts (sodium and chloride) in growing medium. Reduction in radicle and plumule growth at 5 and 6 pH levels may be attributed to high pH concentration in growing media. Balagopalan (1997) reported slow growth of Eucalyptus and Mahogany in acid soil (5.1pH). Better growth at increasing temperatures may be attributed to rapid translocation of reserve food material present in cotyledons.

4.2.2: Water stress

4.2.2.1: Days taken to initiate and complete germination:

Data related to days taken to initiate and complete germination are presented in Table 4.10. Present data revealed that the initiation of germination was also delayed by increasing water stress condition in the species. Days taken to initiate germination was minimum (2days) at -5 bar water stress condition. Maximum days taken to complete germination were recorded in -5 bar water stress condition (7.50 days). Days taken to complete germination were also affected by the increasing water stress condition. There was no germination in -10 and -15 bar. It showed that water stress is an important factor for seed germination in *Jatropha curcas*.

Table 4.10: Effect of different levels of water stress on initiation and completion of germination and germination percentage in *Jatropha curcas*

Water stress levels	Parameters								
	Initiation of germination (days)			Completion of germination (days)			Germination (%)		
	2005	2006	Pooled mean	2005	2006	Pooled mean	2005	2006	Pooled mean
-5 bar	2.00	2.00	2.00	7.00	8.00	7.50	40.00	50.00	45.00
-10 bar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-15 bar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Water is one of the most important inputs essential for the seed germination. Water stress condition affects the seed germination. The days taken to initiate and complete germination, delayed by increasing water stress condition in the species.

Humara *et al.* (2002) reported that excess deficit of water delayed the germination response in *Eucalyptus globules*. Increasing water stress significantly affect the days taken to initiate and complete germination. Mc Donough (1979) also reported that the initiation of germination was delayed by increasing water stress condition in *Populus tremuloides*. Wilson (1971), Mc Donough (1979) and Sah *et al.* (1989) reported that increase in stress may reduce the water uptake, there by retarding the initiation of various metabolic processes due to degradation of essential hydrolytical and other group of enzymes involved in seed germination. Findings of the present study were in conformity with above study. Kramer and Kozlowski (1979) reported that water must be imbibed by the seed to increase protoplasmic hydration and setin motion the chain of metabolic events associated with germination.

4.2.2.2: Germination parameters:

The observations presented in Table 4.11, indicates the effect of water stress on seed germination parameter of *Jatropha curcas*. The seed germination percentage, mean daily germination, rate of germination (GV), vigour index and germination stress index were reduced with increasing water stress condition. The germination

percentage was maximum (45 percent) at -5 bar. It differed significantly from all other treatment. Similar trend was observed for mean daily germination (Table 4.5). The trend was also similar for germination value and the maximum germination value (15.09) was observed at -5 bar which was significantly higher than other treatments. There was drastic reduction in germination value with increase in water stress condition. The maximum (587.50) value of vigour index was recorded at -5 bar. Germination stress index (Table 4.11) was also found maximum (48.03).

Based on experimental data, it can be concluded that water stress conditions significantly affect the germination parameter in *Jatropha curcas*. Saxena *et al.* (1998) studied that the water stress conditions (-5.0, -7.5, -10 and -15 bar) caused inhibition on seed germination. The inhibitory effect of water stress was markedly higher on the seed germination of *P. pinnata* which even failed to germination at -15 bar water stress.

Table 4.11: Effect of different levels of water stress on Mean daily germination, Germination value, Vigour index and Germination stress index in *Jatropha curcas*

Water stress levels	Parameters											
	Mean daily germination			Germination Value			Vigour index			Germination stress index		
	2005	2006	Pooled mean	2005	2006	Pooled mean	2005	2006	Pooled mean	2005	2006	Pooled mean
-5 bar	5.71	6.25	5.98	11.43	18.75	15.09	500.00	675.00	587.50	39.55	56.50	48.03
-10 bar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-15 bar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

But the findings of present investigation showed that reduction in seed germination at higher levels of water stress may possible be attributed to the moisture deficit in the seeds below the threshold which may lead to degradation and inactivation of essential hydrolytical and other groups of enzymes as suggested by Wilson, (1971). Present study concluded that *Jatropha curcas* can grow successfully at

-5 bar water stress condition. This ability of species should give an advantage particularly where water stress level is at -5 bar.

Findings of present study were in conformity of above study and concluded that water stress condition significantly affects the growth behaviour of *Jatropha curcas*.

4.3: Effect of different light and temperature on seed germination:

4.3.1: Days taken to initiate and complete germination and germination percentage:

The perusal of Table 4.12 indicates the effect of different light quality on seed germination, days taken to initiate and complete germination. The seed germination percentage was maximum in control *i.e.* white light (61.22%), followed by followed by red light (47.50%) and far red (42.15), while the seed germination percentage was minimum (27.14%) under dark condition. The germination was significantly higher in control and red light condition as compared to dark condition.

The present data revealed that the initiation of germination was earliest in control *i.e.* white light (1.28 days) followed by red light (1.29 days), far red (1.86 days) and dark condition (3.08). This indicates the significant amount of effect of different light quality.

Similarly, the completion of germination was earliest in control *i.e.* white light (5.57 days) followed by red light (9.22 days), far red (11.50 days) and maximum time was taken under dark condition (12.29 days). Present data revealed that in different light qualities (white, red, far-red and dark) days taken to initiate and complete germination was recorded minimum in white light followed by red light quality.

Ahlawat and Dagar (1980) reported that red light prompted seed germination, yellow and combination of lights showed little effect while blue and green lights initiated germination in *Bidins biternata* a medicinal herb. Singh and Mall (1977), also observed inhibition in green and blue light in *Fagopyrum esculentum*. Rollin

(1959) obtained suppression of germination in infra red and blue light, however, in present investigation red light showed no inhibitory effect.

Table 4.12: Effect of different levels of Light quality on Germination percentage, initiation and completion of germination in *Jatropha curcas* seeds

Light	Parameters								
	Initiation of germination (days)			Completion of germination (days)			Germination (%)		
	2005	2006	Pooled mean	2005	2006	Pooled mean	2005	2006	Pooled mean
Red	1.57	1.10	1.29	10.43	8.00	9.22	46.43	48.57	47.50
Far Red	2.43	1.29	1.86	11.43	11.57	11.50	42.86	41.43	42.15
Dark	2.86	3.29	3.08	12.29	12.29	12.29	25.71	28.57	27.14
Control	1.50	1.05	1.28	5.43	5.71	5.57	65.29	57.14	61.22
SD (0.05)	0.48	0.91	1.37	0.68	1.67	0.65	7.51	7.37	19.42

4.3.2: Germination parameters:

The germination parameters were affected by different light qualities which are summarized in Table 4.13. Mean daily germination in control *i.e.* white light was maximum (11.02) followed by red (5.26), far red (3.67) whereas it was minimum under dark condition (2.21). Mean daily germination in control was significantly higher with respect to red, far red and dark condition.

Table 4.13: Effect of different levels of light quality on Mean daily germination, Germination value and Vigour index in *Jatropha curcas*

Light	Parameters								
	Mean daily germination			Germination Value			Vigour index		
	2005	2006	Pooled mean	2005	2006	Pooled mean	2005	2006	Pooled mean
Red	4.45	6.07	5.26	6.39	21.20	13.80	694.29	1060.00	877.15
Far Red	3.75	3.58	3.67	6.07	5.80	5.94	640.00	853.57	746.79
Dark	2.09	2.32	2.21	2.27	4.78	3.53	331.43	637.94	484.69
Control	12.03	10.01	11.02	18.98	28.77	23.88	1465.71	1098.57	1282.10
LSD (0.05)	0.67	0.59	1.74	1.67	6.69	6.40	142.22	153.36	NS

Mean daily germination was at par with dark and far red condition. The germination value was recorded maximum in control *i.e.* white light (23.88) followed by red light (13.80), far red (5.94) and minimum value (3.53) was recorded in dark light condition. Similar trend was observed in vigour index. Vigour index was found to be maximum (1282.10) in control followed by red light (877.15) and minimum was recorded in dark condition (484.69).

Findings of present investigation revealed that different qualities of light affect the germination parameter in *Jatropha curcas*. Ahlawat and Dagar (1980) recorded 80% seed germination in *Bidens biternata* under red light condition, whereas; in control recorded 70% germination. Sah *et al.* (1989) studied the effect of different light quality on *Pinus species* and recorded that *P. roxburghii* showed 100% germination in direct and red light, whereas, *p. wallichiana* and *P. greggii* had maximum germination in red light. Silva and Mathos (1998) studied that the seeds of *Triplaris surinamensis* germinated better under white (63-73%) and red light (65-66%) than under far red or no light (both 50.21%). Naidu and Amritphale (2001) reported that single red light exposure could induce germination of more than 70% of the seeds in *Caesulia axillaries* Roxb. Khanna (2000) reported that plants grown in blue light are small. Red light on the other hand results in elongation of cells giving the appearance of etiolated plants. Violet and ultra-violet light bring about dwarfing effect. In present study similar trend of germination percentage recorded for germination value, mean daily germination and vigour index.

4.4: Effect of temperature on seed germination:

4.4.1: Days taken to initiate and complete germination and germination percentage:

Days taken to initiate and complete germination as influenced by different level of temperature are presented in Table 4.14. The days taken to initiate germination was minimum (1.43 days) at 30°C whereas it was maximum (2.36 days) at 25°C. Days taken to initiate germination at 35°C was 2.22 days. Days taken to

initiate germination at 25°C and 35°C was significantly higher than at 30°C. The days taken to complete germination was minimum (7.79 days) at 30°C whereas it was maximum (11.79 days) at 25°C. Days taken to initiate germination at 35°C was 10.93 days. Days taken to initiate germination at 25°C and 35°C was significantly higher than at 30°C.

Data presented in Table 4.14, reflected that maximum germination percentage (67.86) was recorded at 30°C, followed by 35°C (37.86%) whereas minimum germination (30%) was recorded at 25°C. The germination percent at 25°C and 35°C was significantly at par but significantly lower than germination percent at 30°C.

Table 4.14: Effect of different levels of temperatures on initiation and completion of germination and germination percentage in *Jatropha curcas*

Temperature	Parameters								
	Initiation of germination (days)			Completion of germination (days)			Germination (%)		
	2005	2006	Pooled mean	2005	2006	Pooled mean	2005	2006	Pooled mean
25	2.00	2.71	2.36	11.43	12.14	11.79	34.29	25.71	30.00
30	1.29	1.57	1.43	9.14	6.43	7.79	62.86	72.86	67.86
35	2.00	2.43	2.22	10.43	11.43	10.93	40.00	35.71	37.86
SD (0.05)	NS	NS	0.45	0.83	2.26	0.81	10.99	18.05	14.55

Temperature is one of the most important factors in the germination of seeds and each species has specific requirement of temperature under which it yields the maximum germination. Data revealed that seed germination increased with increase in temperature from 30 to 35°C and then there was a reduction in germination with further increase in temperature. Temperature is known to influence seed germination.

Various tree species respond differently to temperature during germination. In *Jatropha curcas*, the days taken to initiate and complete germination varies in different temperature level and minimum values recorded at 25°C and maximum at 35°C. Woody plants germinate well over a wide range of temperature. Optimum temperature for germination of tropical species has been reported for *Azadirachta*

indica 25⁰C, *Bombax ceiba* 25⁰C, *Eucalyptus camaldulensis* 30⁰C, *Leucaena leucocephala* 30⁰C, *Prosopis cineraria* 30⁰C and *Tectona grandis* 30⁰C by Bonner *et al.*, (1994). Some species are reported to germinate better under alternating temperatures (*Acacia* species and Tropical pines). At optimum temperature enzymatic activity starts quickly in presence of moisture, so as to mobilize food material and augment germination. Sah *et al.* (1989) reported that all the species of *Pinus* (*P. roxburghii*, *p. wallichiana*, *P. patula* and *P. greggii*) completed their germination between 27 and 30 days under 25⁰C. At 30⁰C all the species completed their germination within 27 days. Chasmashama and Downs (1982) reported that germination was significantly retarded by a constant temperature of 35⁰C in light and 30⁰C in dark in *Chlorophora excelsa* seed. Kaushik *et al.* (1995) reported that the seed germination of *Sesamum indicum* was influenced by different treatment of temperatures (20, 25 and 30⁰C). Tekety (1996) studied that incase of *Tamarindus indica* germination was totally inhibited at 10⁰C. The optimum temperature for germination (98%) is around 25⁰C. Al-Mudaris *et al.* (1998) reported that increase in temperature from 15 to 30⁰C improved seed germination and reduced days taken to initiate and complete germination in *Acacia* spp. This may be attributed to fast imbibitions of water by seeds and induced enzymatic activities necessary for germination.

4.4.2. Germination parameters:

Present data revealed that seed germination in *Jatropha curcas* was influenced by different range of temperatures. The temperature is one of the most important factors in the seed germination of *Jatropha curcas* and the species has specific requirement of temperature under which it yield the maximum germination. Data presented in Table 4.15, reflected that vigour index was found to be maximum (1139.3) at 30⁰C temperature, which was significantly higher than other treatments. Minimum vigour index (414.43) was observed at 25⁰C temperature followed by 35⁰C (521.07). Among all the treatments, treatment (30⁰C) excelled for all the germination

related parameters and recorded maximum values for mean daily germination (9.11) and germination value (39.21), which was significantly higher than other treatments. These parameters were lowest at temperature 25°C viz., mean daily germination (2.56), germination value (6.20) and vigour index (414.43).

Table 4.15: Effect of different levels of temperatures on mean daily germination, germination value and vigour index in *Jatropha curcas*

Temperature	Parameters								
	Mean daily germination			Germination Value			Vigour index		
	2005	2006	Pooled mean	2005	2006	Pooled mean	2005	2006	Pooled mean
25	3.00	2.12	2.56	7.07	5.33	6.20	431.71	397.14	414.43
30	6.88	11.33	9.11	23.90	54.52	39.21	994.29	1284.34	1139.3
35	3.84	3.12	3.48	11.17	9.23	10.20	540.00	502.14	521.07
SD (0.05)	1.49	3.63	1.80	6.38	19.87	17.76	216.91	352.26	298.20

It was clear from the data that 30°C and above temperature is suitable for seed germination related parameters and seeds are not responding well below these ranges of temperature. Similarly, the effect of temperature on seed germination has been widely worked out. Gupta and Pattanath (1979) reported that *Pongamia pinnata* showed non-significant difference in germination percentage under different condition of temperature (30°C and 35°C). Shringirishi *et al.* (2001) reported that the maximum germination percent and mean daily germination (MDG) was obtained at 30°C in neem (*A. indica*) seeds. Mossler *et al.* (1993) reported that seeds of *Acer oblongum*, *Anogeissus latifoli*, *Kydia calyeiana*, *Sapindus mukorossi*, *Terminalia bellerica* and *Terminalia chebula* showed germination at 10°C. An increase in temperature upto 25°C after 10 days significantly improved germination. Findings of present study are in conformity with above study, which showed that days taken to initiate and complete germination reduced with increase in temperature. Al-Mudaris *et al.* (1998) reported that increase in temperature from 15 to 30°C improved seed germination and reduced days taken to initiate and complete germination in *Acacia*

species. This may be attributed to fast imbibitions of water by seeds and induced enzymatic activities necessary for germination. Similarly, effect of temperature on seed germination has been widely worked out. Borges *et al.* (1998) reported that 30°C temperature favoured the seed germination and seedling growth of polyembryonic mango varieties Espida and Uba under laboratory conditions of Brazil. Maximum germination in *Pinus patula* has been reported at 30°C (Negi *et al.*, 1994). Omari (1993) reported that the maximum and best germination occurred at 15°C *Acacia* spp. Lima *et al.* (1997) studied that the rate of seed germination increased with increasing temperature (10.9°C-42.4°C). Andrade *et al.* (2000) found that constant temperatures of 25, 30 and 35°C gave the best germination in Genipap (*Genipa Americana*) in Brazil. Thailiyal and Rawat (1991) reported maximum germination of *Alnus nepalensis* and *A. nilotica* at 25°C. Sah and Singh (1995) reported maximum germination *Populus ciliata* at 20°C. Bonner *et al.* (1994) opined that the effects of temperature, light and moisture on seed germination are integrated. Germination usually occurs over a wide range of temperature. The enzymatic activity essential for seed germination is speeded up at increased temperature and thereby results in quick seed germination.

Field Experiments

4.5: Effect of time and depth of sowing on germination and seedling growth of *Jatropha curcas*:

4.5.1: Days taken to initiate and complete germination:

Time and depth of seed sowing influenced seed germination in *Jatropha curcas*. Observations on days taken to initiate and complete germination are presented in Table 4.16. Minimum number of days taken to initiate germination was registered at 2cm depth in different months of sowing, while those sown at 4cm depth took maximum days to initiate germination. Month of March was found to be the best in comparison of other months.

Data on initiation of germination reveals that the days taken to initiate germination was minimum in the month of March (6.38 days) and maximum was in the month of November (13.92 days). In the month of July, days taken to initiate germination was 7.13 days which was at par with month of March. However, days taken to initiate germination in the month of November was significantly higher from the month of March and July. Similarly, table indicates that, days taken to initiate germination was minimum at 2cm depth (7.28 days), followed by 1cm depth (8.78days), 3cm depth (9.48 days) and maximum was at the depth of 4cm (11.03 days). In general time taken to initiate germination increased with increase in depth of sowing through out the period of study. Days taken to initiate germination at 4cm depth was significantly higher than 1, 2 and 3cm depth. Days taken to initiate germination at depth 1cm and 3 cm were statistically at par. When we see the effect of depth of sowing in different months, sowing at the depth of 2cm was found to be best in different months of sowing *i.e.* March (4.67 days) followed by July (5.17 days) and initiation of germination was maximum in the month of November (12 days).

Data on completion of germination reveals that the days taken to complete germination was minimum in the month of March (11.59 days) and maximum was in the month of November (19.21 days). In the month of July, days taken to complete germination was 11.96 days which was at par with month of March. Days taken to complete germination was influenced by time and depth of seed sowing through out the period of study. However, days taken to complete germination in the month of November was significantly higher from the month of March and July. Similarly, table indicates that, days taken to complete germination was minimum at 2cm depth (12.50 days), followed by 1cm depth (13.88 days), 3cm depth (14.31 days) and maximum was at the depth of 4cm (16.28 days). Days taken to complete germination at 4cm depth was significantly higher than 1, 2 and 3cm depth. Days taken to complete germination at depth 1cm and 3cm were statistically at par. When we see the effect of depth of sowing in different months, sowing at the depth of 2cm was

found to be best in different months of sowing *i.e.* March (9.84 days) followed by July (10.34 days) and November (17.43 days).

It had been apparent from the data that time and depth of sowing both influences initiation and completion of seed germination. The effect of time of sowing may be attributed to variation in weather conditions in respective of months, which control plant physiological activities. Further adverse effect of greater sowing depth on days taken to initiate and complete germination may be attributed to micro environments provided on soil surface. Greater depths might have inhibited emergence of cotyledons on account of compactness of top soil. Present results showed that the seed germination was completed within 15-20 days of seed sowing.

Low germination was recorded in the month of winter (November). It may be attributed to the fact that the low temperature may be not suitable for seed germination of *Jatropha curcas*. Low temperature might have induced dormancy in seed on account of slow physiological activities with in the seed. Quick germination in March-July may be attributed to congenial conditions for seed germination. Arjunan *et al.* (1994) reported that the best depth for germination of *Pongamia pinnata* seeds is 0.5 to 1cm. Similar observations were recorded in the present study with regards to sowing time and depth. Beniwal *et al.* (2004) reported the time of seed sowing greatly influenced germination and seedling growth in *Jatropha curcas*.

Chandra and Ram (1980) reported seed sowing deeper than 15mm delayed germination significantly in Deodar. Padma and Reddy (1998) found that time taken for germination in mango was 17.8, 33 and 23.4 days when seed placed at depth of 1, 2 and 4cm, respectively. The minimum time taken for 50% germination of seeds at 1cm depth was 29.9 days. Prasad *et al.* (1988) reported that May is the best month for seed sowing in Chironjee and recorded 15.5% germination after 20 days of seed sowing. Anonymous (1985) reported that June-July is optimum time for mango sowing under north Indian conditions. In Ber, Kajal and Singhrot (1986) reported quick germination when seeds were sown at 2cm depth. This is in accordance with Anonymous (1981), who reported that 30% plant of chironjee can be obtained by

direct sowing at a depth of 0.6 cm at the commencement of monsoon rains in Uttar Pradesh.

A number of factors are responsible for low germination percentage in the nursery and the depth of sowing appears to be an important factor which affects the seed germination. Germination percentage decreased while increasing soil depth.

Germination percentage of *Jatropha curcas* as affected by time and depth of sowing are presented in Table 4.16. Present data revealed that maximum (72.51%) germination was recorded during the month of March after 20 days of sowing which was significantly higher than that of other months followed by July (61.51) and minimum (50.17) germination percentage was recorded in the month of November. Similarly, table indicates that germination percentage was maximum at 2cm depth (69.45%) followed by 1cm depth (63.12 %), 3cm depth (58.56%) and minimum was at the depth of 4cm (54.44%). Germination percentage at 4 cm depth was significantly lower than 1 and 2cm depth. Germination percentage at depth 1cm and 3cm were statistically at par. Germination percentage at 2cm depth was significantly higher than 3 and 4cm depth. When we see the effect of depth of sowing in different months, sowing at the depth of 2 cm was found to be best in different months of sowing i.e. March (83.34%) followed by July (70%) and November (55.00%).

Seeds sown at higher depth (4cm) exhibited less germination percentage as compared to other depths. Low seed germination was recorded during the winter season at all the depths after 20 days of sowing period due to very low temperature.

The results indicate that the germination was best in the month of March at 2cm depth of sowing and decreased steadily at greater depth (4cm) depth. Time and depth of sowing influenced the germination percentage in *Jatropha curcas* seeds. The germination percentage of seeds decreases with increase the depth of sowing.

Umarani *et al.* (1997) reported that largest seeds of *C. equisetifolia* sown at 1cm depth gave 58% germination. Ponnammal *et al.* (1993) reported that the best depth for germination of neem seeds was 0.5-1cm.

Table 4.16: Effect of time and depth of sowing on initiation and completion of germination and germination percentage in *Jatropha curcas* seeds and seedling growth

h)	2005			2006			Mean			Pooled Mean
	March	July	Nov.	March	July	Nov.	March	July	Nov.	
on of germination (days)										
	6.00	6.67	13.67	5.67	6.00	14.67	5.84	6.34	14.17	8.78
	4.33	5.00	11.67	5.00	5.33	12.33	4.67	5.17	12.00	7.28
	7.00	7.33	13.2	6.67	7.67	15.00	6.84	7.50	14.10	9.48
	7.67	9.00	14.33	8.67	10.00	16.50	8.17	9.50	15.42	11.03
n	6.25	7.00	13.22	6.50	7.25	14.63	6.38	7.13	13.92	9.14
(05)	M(0.92)	D(1.07)	M x D(NS)	M(0.75)	D(0.81)	M x D(NS)	M(2.37)	D(0.87)	M x D(NS)	
etion of germination (days)										
	11.00	11.33	19.60	10.67	11.00	19.67	10.84	11.17	19.64	13.88
	9.67	10.00	16.67	10.00	10.67	18.00	9.84	10.34	17.43	12.50
	11.33	11.67	19.50	11.67	12.00	19.70	11.50	11.84	19.60	14.31
	14.33	14.67	19.67	14.00	14.33	20.67	14.17	14.50	20.17	16.28
n	11.58	11.92	18.86	11.59	12.00	19.51	11.59	11.96	19.21	14.24
(05)	M(0.53)	D(0.69)	M x D(1.14)	M(0.69)	D(0.81)	M x D(NS)	M(0.66)	D(0.75)	M x D(1.32)	
ination (%)										
	70.00	62.00	50.00	76.67	66.70	53.33	73.34	64.35	51.67	63.12
	80.00	66.67	53.33	86.67	73.33	56.67	83.34	70.00	55.00	69.45
	66.67	60.00	48.00	70.00	56.67	50.00	68.34	58.34	49.00	58.56
	63.33	53.33	43.33	66.67	53.33	46.67	65.00	53.33	45.00	54.44
an	70.00	60.50	48.67	75.00	62.51	51.67	72.51	61.51	50.17	61.39
(005)	M(5.65)	D(6.53)	M x D (NS)	M(4.66)	D(NS)	M x D(NS)	M(5.31)	D (6.13)	M x D(NS)	

M: Month, D: Depth, M*D: Month*Depth

Arya and Singh (1996) reported that the seed germination in *Ulmus laevigata* was best (29.8%) at 1cm depth and decreased steadily at greater depths (to only 1.32%) at 4cm depth. In Ber, Kajal and Singhrot (1986) reported quick germination when seeds were sown at 2cm depth.

However, Li and Wardle (1999) reported in *Hippophae* species that surface sowing give higher percentage of seedling emergence and more rapid completion of emergence as compared to 1 or 2cm depth. These findings are in accordance with Arjunan *et al.* (1994), who reported that the best depth for germination of *Pongamia pinnata* seeds is 0.5-1cm larger seed possessed higher percentage (98%) of

germination at 1cm depth. On the contrary, Sehgal and Singh (1990) found that 2cm depth of sowing is most appropriate for germination of *Pistachia integrima*. Akinola *et al.* (1999) reported that maximum seed germination in subabool in light soil was obtained at 6cm depth of sowing, while in heavy soil at 2cm depth.

4.5.2: Germination parameters and biomass yield as influenced by depth of sowing:

The growth performance of the seedlings germinated at different depths revealed that there was a significant difference in the shoot length of *Jatropha curcas* seedlings germinated over the year in the nursery condition. Data related to seedling growth and biomass production are presented in Table 4.17.

4.5.2.1: Seedling growth:

Seedling growth was recorded in terms of plant height and collar diameter at monthly interval up to four months of seed sowing. The inferences have been drawn and discussed in light of available literature.

Table 4.17: Effect of time and depth of sowing on different growth parameters in *Jatropha curcas*

DAS	Soil Depth (cm)	2005			2006			Mean			Pooled Mean
		March	July	Nov.	March	July	Nov.	March	July	Nov.	
Plant height (cm)											
30	1	29.78	19.45	7.87	23.33	15.59	6.71	26.56	17.52	7.29	17.12
	2	31.96	22.03	7.90	30.21	16.01	6.85	31.09	19.02	7.38	19.16
	3	28.36	19.27	7.86	20.33	15.28	6.30	24.35	17.28	7.08	16.24
	4	27.17	18.53	7.67	19.38	14.32	5.60	23.28	16.43	6.64	15.45
	Mean	29.32	19.82	7.83	23.31	15.30	6.37	26.32	17.56	7.10	16.99
	LSD(0.05)	M(2.67)	D(NS)	M xD(NS)	M(2.39)	D(1.00)	M xD(NS)	M(2.28)	D(NS)	M xD(NS)	
60	1	35.68	31.29	9.23	27.40	22.21	7.32	31.54	26.75	8.28	22.19
	2	38.44	33.47	9.85	32.54	25.34	7.41	35.49	29.41	8.63	24.51
	3	34.81	27.64	9.00	24.75	19.94	6.90	29.78	23.79	7.95	20.51
	4	34.66	27.27	7.90	23.84	19.78	6.10	29.25	23.53	7.00	19.93
	Mean	35.90	29.92	9.00	27.13	21.82	6.93	31.52	25.87	7.97	21.79
	LSD(0.05)	M(2.77)	D(NS)	M xD(NS)	M(1.63)	D(1.90)	M xD(NS)	M(1.90)	D(2.18)	M xD(NS)	

1	46.10	36.89	10.30	33.11	28.86	7.42	39.61	32.88	8.86	27.12
2	47.25	41.00	10.42	34.50	34.80	7.59	40.88	37.90	9.01	29.26
3	41.00	35.92	9.19	31.67	26.00	7.21	36.34	30.96	8.20	25.17
4	40.84	35.83	9.17	28.79	24.50	7.13	34.82	30.17	8.15	24.38
Mean	43.80	37.41	9.77	32.02	28.54	7.34	37.91	32.98	8.56	26.48
LSD(0.05)	M(2.60)	D(NS)	M x D(NS)	M(2.16)	D(2.48)	M x D(NS)	M(2.24)	D(2.60)	M x D(NS)	
1	55.50	42.00	11.8	45.24	35.33	8.83	50.37	38.67	10.32	33.12
2	56.00	43.00	12.30	48.25	37.67	9.33	52.13	40.34	10.82	34.43
3	54.17	38.03	11.7	41.75	33.00	8.20	47.96	35.52	9.95	31.14
4	48.33	36.80	10.32	35.64	32.07	8.13	41.99	34.44	9.23	28.55
Mean	53.50	39.96	11.53	42.72	34.52	8.62	48.11	37.24	10.08	31.81
LSD(0.05)	M(3.83)	D(NS)	M x D(NS)	M(3.98)	D(NS)	M x D(NS)	M(5.14)	D(5.23)	M x D(NS)	
Stem diameter (cm)										
1	0.69	0.64	0.60	0.69	0.59	0.58	0.69	0.62	0.59	0.63
2	0.76	0.70	0.63	0.77	0.63	0.62	0.77	0.67	0.63	0.69
3	0.68	0.63	0.55	0.64	0.58	0.54	0.66	0.61	0.55	0.61
4	0.65	0.63	0.51	0.58	0.54	0.51	0.615	0.59	0.51	0.57
Mean	0.70	0.65	0.57	0.67	0.59	0.56	0.68	0.62	0.57	0.62
LSD(0.05)	M(0.11)	D(NS)	M x D(NS)	M(0.04)	D(NS)	M x D(NS)	M(0.04)	D(NS)	M x D(NS)	
1	0.88	0.76	0.75	0.90	0.76	0.66	0.89	0.76	0.71	0.79
2	0.93	0.78	0.76	0.94	0.89	0.67	0.94	0.84	0.72	0.83
3	0.83	0.75	0.73	0.83	0.72	0.65	0.83	0.74	0.69	0.75
4	0.82	0.74	0.70	0.74	0.64	0.59	0.78	0.69	0.65	0.71
Mean	0.87	0.76	0.74	0.85	0.75	0.64	0.86	0.76	0.69	0.77
LSD(0.05)	M(NS)	D(NS)	M x D(NS)	M(0.20)	D(NS)	M x D(0.02)	M(0.05)	D(NS)	M x D(0.07)	
1	1.14	1.00	0.80	1.16	1.10	0.73	1.15	1.05	0.77	0.99
2	1.22	1.10	0.82	1.18	1.15	0.76	1.20	1.13	0.79	1.04
3	1.02	0.93	0.79	1.01	0.87	0.73	1.02	0.90	0.76	0.89
4	1.00	0.92	0.77	0.97	0.86	0.68	0.99	0.89	0.73	0.87
Mean	1.10	0.99	0.80	1.08	1.00	0.73	1.09	0.99	0.76	0.95
LSD(0.05)	M(0.02)	D(NS)	M x D(NS)	M(0.20)	D(NS)	M x D(NS)	M(0.16)	D(0.17)	M x D(NS)	
1	1.30	1.20	0.92	1.35	1.16	0.83	1.33	1.18	0.88	1.13
2	1.70	1.25	0.95	1.45	1.17	0.90	1.58	1.21	0.93	1.24
3	1.25	1.14	0.90	1.23	1.13	0.78	1.24	1.14	0.84	1.07
4	1.23	1.09	0.87	1.13	1.06	0.74	1.18	1.08	0.81	1.02
Mean	1.37	1.17	0.91	1.29	1.13	0.81	1.33	1.15	0.87	1.12
LSD(0.05)	M(0.22)	D(0.05)	M x D(NS)	M(0.24)	D(NS)	M x D(NS)	M(0.15)	D(0.12)	M x D(NS)	
Total dry weight (g)										
1	1.35	1.12	0.62	1.44	1.43	0.26	1.4	1.28	0.44	1.04
2	1.61	1.33	0.67	2.64	2.02	0.43	2.13	1.68	0.55	1.45
3	1.24	0.99	0.38	1.20	1.12	0.25	1.22	1.06	0.32	0.87
4	0.75	0.54	0.34	0.90	0.77	0.19	0.83	0.66	0.27	0.59
Mean	1.24	1.00	0.50	1.55	1.34	0.28	1.40	1.17	0.40	0.99
LSD(0.05)	M(NS)	D(NS)	M x D(NS)	M(0.44)	D(0.53)	M x D(NS)	M(0.53)	D(0.69)	M x D(NS)	
1	4.22	3.49	0.98	3.09	2.69	0.48	3.70	3.09	0.73	2.51
2	5.43	5.41	1.32	3.67	3.33	0.65	4.55	4.37	0.99	3.30
3	3.35	3.40	0.75	2.07	2.04	0.43	2.71	2.72	0.59	2.01
4	2.36	1.78	0.62	1.57	1.06	0.36	1.97	1.42	0.49	1.29
Mean	3.84	3.52	0.92	2.60	2.28	0.48	3.23	2.90	0.70	2.28
LSD(0.05)	M(1.20)	D(NS)	M x D(NS)	M(0.62)	D(0.75)	M x D(NS)	M(1.07)	D(0.18)	M x D(NS)	
1	5.96	5.92	1.38	5.38	4.11	0.71	3.05	3.05	2.75	2.95
2	11.28	6.37	1.42	6.42	4.65	0.93	3.65	3.55	2.55	3.25

	3	5.48	4.94	0.90	4.95	2.72	0.60	3.00	2.75	2.55	2.77
	4	4.53	4.27	0.80	4.85	2.00	0.59	3.35	2.20	2.70	2.75
	Mean	6.81	5.38	1.13	5.40	3.37	0.71	3.26	2.89	2.64	2.93
	LSD(0.05)	M(1.66)	D(NS)	M x D(NS)	M(0.92)	D(0.33)	M x D(NS)	M(0.21)	D(0.29)	M x D(NS)	
	1	11.03	6.97	1.65	12.34	5.71	2.04	4.25	3.60	2.70	3.52
	2	12.07	7.95	2.54	15.97	7.25	2.10	4.30	3.25	2.80	3.45
	3	8.87	6.84	1.59	8.82	4.26	1.33	3.70	3.45	2.30	3.15
	4	5.94	5.75	1.52	8.59	2.71	1.22	3.30	2.65	2.85	2.93
	Mean	9.48	6.88	1.83	11.43	4.98	1.67	3.89	3.24	2.66	3.26
	LSD(0.05)	M(2.52)	D(NS)	M x D(NS)	M(2.63)	D(NS)	M x D(NS)	M(0.92)	D(0.09)	M x D(NS)	
Relative Growth Rate ($\text{g g}^{-1} \text{d}^{-1}$)											
	1	0.040	0.050	0.020	0.010	0.019	0.014	0.024	0.036	0.016	0.025
	2	0.040	0.04	0.014	0.027	0.022	0.023	0.034	0.030	0.019	0.028
	3	0.040	0.035	0.024	0.021	0.011	0.022	0.029	0.023	0.023	0.025
	4	0.030	0.045	0.019	0.022	0.021	0.020	0.027	0.033	0.020	0.027
	Mean	0.038	0.043	0.019	0.020	0.018	0.020	0.029	0.031	0.020	0.027
	1	0.020	0.006	0.009	0.020	0.011	0.011	0.022	0.009	0.010	0.014
	2	0.020	0.020	0.013	0.020	0.013	0.013	0.020	0.016	0.013	0.016
	3	0.020	0.034	0.008	0.035	0.018	0.015	0.028	0.026	0.012	0.022
	4	0.013	0.013	0.012	0.030	0.008	0.011	0.022	0.011	0.012	0.015
	Mean	0.020	0.020	0.010	0.030	0.010	0.010	0.020	0.020	0.010	0.017
	1	0.020	0.003	0.007	0.029	0.030	0.016	0.023	0.020	0.013	0.019
	2	0.006	0.020	0.006	0.035	0.024	0.013	0.025	0.021	0.015	0.020
	3	0.021	0.009	0.009	0.020	0.022	0.012	0.022	0.019	0.012	0.018
	4	0.021	0.020	0.010	0.022	0.018	0.016	0.020	0.018	0.011	0.016
	Mean	0.020	0.010	0.010	0.030	0.020	0.010	0.023	0.020	0.013	0.019
Net Assimilatory Rate ($\text{mg cm}^{-2} \text{d}^{-1}$)											
	1	0.22	0.38	0.16	0.06	0.13	0.10	0.14	0.26	0.13	0.18
	2	0.21	0.32	0.18	0.19	0.19	0.14	0.20	0.26	0.16	0.21
	3	0.16	0.32	0.23	0.07	0.11	0.12	0.12	0.22	0.18	0.17
	4	0.17	0.22	0.30	0.09	0.05	0.16	0.13	0.14	0.23	0.17
	Mean	0.19	0.31	0.22	0.10	0.12	0.13	0.15	0.22	0.18	0.18
	1	0.21	0.04	0.06	0.12	0.08	0.10	0.17	0.06	0.08	0.10
	2	0.11	0.15	0.11	0.13	0.10	0.08	0.12	0.12	0.09	0.11
	3	0.11	0.09	0.07	0.17	0.06	0.06	0.14	0.08	0.06	0.09
	4	0.15	0.22	0.06	0.21	0.08	0.09	0.18	0.15	0.08	0.14
	Mean	0.15	0.13	0.08	0.16	0.08	0.08	0.15	0.10	0.08	0.11
	1	0.02	0.07	0.13	0.27	0.13	0.20	0.16	0.14	0.10	0.13
	2	0.13	0.05	0.05	0.19	0.13	0.22	0.17	0.15	0.10	0.14
	3	0.13	0.08	0.11	0.14	0.11	0.12	0.14	0.12	0.09	0.12
	4	0.07	0.08	0.14	0.16	0.05	0.11	0.13	0.11	0.06	0.10
	Mean	0.09	0.07	0.11	0.19	0.11	0.16	0.15	0.13	0.09	0.12
Specific Leaf weight (mg cm^{-2})											
	1	5.00	3.80	2.90	4.50	3.80	2.60	4.75	3.80	2.80	3.78
	2	6.00	4.60	3.00	5.80	3.90	2.40	5.90	4.25	2.70	4.28
	3	4.60	3.50	1.90	4.30	3.80	3.70	4.45	3.65	2.80	3.63
	4	4.50	3.30	1.90	4.00	2.30	2.20	4.25	2.80	2.10	3.05
	Mean	5.03	3.80	2.43	4.65	3.45	2.73	4.84	3.63	2.60	3.69
	1	3.30	3.40	2.80	3.50	3.50	2.50	3.40	3.50	2.70	3.20
	2	3.90	3.50	2.90	4.40	4.20	3.90	4.15	3.85	3.40	3.80
	3	3.50	3.30	4.10	3.20	3.10	2.40	3.35	3.20	3.25	3.27
	4	3.40	2.20	3.50	2.80	2.20	2.00	3.10	2.20	2.80	2.70
	Mean	3.53	3.10	3.33	3.48	3.25	2.70	3.50	3.19	3.04	3.24
	1	3.50	4.00	2.80	2.70	2.60	2.50	3.10	3.30	2.70	3.03
	2	4.30	4.30	2.80	3.00	2.80	2.50	3.65	3.55	2.65	3.28
	3	3.10	2.70	2.60	2.60	2.40	2.40	2.85	2.55	2.50	2.63
	4	3.00	2.60	2.60	2.50	2.40	2.20	2.75	2.50	2.40	2.55

	Mean	3.48	3.40	2.70	2.70	2.55	2.40	3.09	2.98	2.56	2.88
20	1	4.00	3.30	3.00	4.50	3.90	2.40	4.25	3.60	2.70	3.52
	2	4.10	3.50	3.10	4.50	4.00	2.70	4.30	3.75	2.90	3.65
	3	3.10	2.10	2.10	3.80	3.70	2.50	3.45	2.90	2.30	2.88
	4	3.20	2.90	2.20	3.80	2.50	2.40	3.50	2.70	2.30	2.83
	Mean	3.60	2.95	2.60	4.15	3.53	2.50	3.88	3.24	2.55	3.22
Root : Shoot ratio											
	1	0.40	0.35	0.24	0.30	0.22	0.21	0.35	0.29	0.23	0.29
	2	0.45	0.44	0.30	0.48	0.41	0.30	0.47	0.43	0.30	0.40
	3	0.34	0.23	0.22	0.29	0.25	0.20	0.32	0.24	0.21	0.26
	4	0.38	0.23	0.19	0.24	0.23	0.20	0.31	0.23	0.20	0.25
	Mean	0.39	0.31	0.24	0.33	0.28	0.23	0.36	0.30	0.24	0.30
	LSD (0.05)	M(NS)	D(NS)	M x D(NS)	M(NS)	D(NS)	M x D(NS)	M(NS)	D(NS)	M x D(NS)	
	1	0.22	0.22	0.19	0.37	0.33	0.33	0.30	0.28	0.26	0.28
	2	0.29	0.23	0.23	0.40	0.37	0.37	0.35	0.30	0.30	0.32
	3	0.23	0.22	0.21	0.30	0.30	0.28	0.27	0.26	0.25	0.26
	4	0.22	0.16	0.16	0.25	0.25	0.24	0.24	0.21	0.13	0.19
	Mean	0.24	0.21	0.20	0.33	0.31	0.31	0.29	0.26	0.24	0.26
	LSD (0.05)	M(NS)	D(0.06)	M x D(NS)	M(NS)	D(NS)	M x D(NS)	M(NS)	D(NS)	M x D(NS)	
	1	0.28	0.23	0.23	0.26	0.20	0.20	0.27	0.22	0.22	0.24
	2	0.31	0.27	0.26	0.27	0.24	0.23	0.29	0.26	0.25	0.27
	3	0.22	0.22	0.21	0.25	0.25	0.22	0.24	0.24	0.22	0.23
	4	0.21	0.21	0.20	0.24	0.23	0.22	0.23	0.22	0.21	0.22
	Mean	0.26	0.23	0.23	0.26	0.23	0.22	0.26	0.24	0.23	0.24
	LSD (0.05)	M(NS)	D(NS)	M x D(NS)	M(NS)	D(NS)	M x D(NS)	M(NS)	D(NS)	M x D(NS)	
	1	0.24	0.20	0.20	0.25	0.22	0.20	0.25	0.21	0.20	0.22
	2	0.26	0.22	0.22	0.27	0.21	0.21	0.27	0.22	0.22	0.24
	3	0.24	0.21	0.22	0.25	0.21	0.20	0.25	0.21	0.21	0.22
	4	0.23	0.22	0.21	0.20	0.20	0.19	0.22	0.21	0.20	0.21
	Mean	0.24	0.21	0.21	0.24	0.21	0.20	0.25	0.21	0.21	0.22
	LSD (0.05)	M(0.02)	D(NS)	M x D(NS)	M(0.07)	D(NS)	M x D(NS)	M(0.04)	D(NS)	M x D(NS)	
Above ground biomass (g)											
	1	1.23	0.97	0.55	1.32	1.28	0.22	1.28	1.13	0.39	0.93
	2	1.49	1.15	0.59	2.10	1.55	0.37	1.80	1.35	0.48	1.21
	3	1.15	0.86	0.34	1.13	1.06	0.22	1.14	0.96	0.28	0.79
	4	0.70	0.45	0.30	0.83	0.72	0.20	0.77	0.59	0.25	0.54
	Mean	1.14	0.86	0.45	1.35	1.15	0.25	1.25	1.01	0.35	0.87
	LSD (0.05)	M(NS)	D(NS)	M x D(NS)	M(0.44)	D(NS)	M x D(NS)	M(0.44)	D(0.53)	M x D(NS)	
	1	3.84	3.08	0.87	2.67	2.30	0.42	3.26	2.69	0.65	2.20
	2	4.95	4.77	1.02	3.13	2.90	0.57	4.04	3.84	0.80	2.89
	3	2.99	2.92	0.67	1.78	1.81	0.36	2.39	2.37	0.52	1.76
	4	2.15	1.52	0.55	1.37	0.91	0.26	1.76	1.22	0.41	1.13
	Mean	3.48	3.07	0.78	2.24	1.98	0.40	2.86	2.53	0.60	2.00
	LSD(0.05)	M(1.10)	D(NS)	M x D(NS)	M(0.62)	D(0.75)	M x D(NS)	M(0.87)	D(1.00)	M x D(NS)	
	1	5.24	5.09	1.17	4.67	3.56	0.60	4.96	4.33	0.89	3.39
	2	10.09	5.88	1.24	5.60	3.64	0.79	7.85	4.76	1.02	4.54
	3	4.82	4.64	0.77	4.25	2.44	0.53	4.54	3.54	0.65	2.91
	4	3.86	3.73	0.69	4.23	1.80	0.51	4.05	2.77	0.60	2.47
	Mean	6.00	4.84	0.97	4.69	2.86	0.61	5.35	3.85	0.79	3.33
	LSD(0.05)	M(1.48)	D(NS)	M x D(NS)	M(0.81)	D(0.92)	M x D(NS)	M(1.31)	D(1.51)	M x D(NS)	
120	1	9.77	6.19	1.43	10.81	3.74	1.74	10.29	4.97	1.59	5.62
	2	10.77	6.82	2.18	13.88	6.29	1.79	12.33	6.56	1.99	6.96
	3	7.92	5.83	1.34	7.83	3.67	1.15	7.88	4.75	1.25	4.63

4	5.10	5.13	1.28	7.50	2.37	1.08	6.30	3.75	1.18	3.74
Mean	8.39	5.99	1.56	10.01	4.02	1.44	9.20	5.01	1.50	5.24
LSD(0.05)	M(2.33)	D(NS)	M xD(NS)	M(2.35)	D(NS)	M xD(NS)	M(2.67)	D(1.00)	M xD(NS)	
low ground biomass (g)										
1	0.11	0.14	0.08	0.11	0.15	0.03	0.11	0.15	0.06	0.11
2	0.12	0.17	0.08	0.54	0.47	0.06	0.33	0.32	0.07	0.24
3	0.09	0.13	0.05	0.07	0.07	0.03	0.08	0.10	0.04	0.07
4	0.046	0.09	0.04	0.07	0.05	0.03	0.06	0.07	0.03	0.05
Mean	0.09	0.13	0.06	0.20	0.19	0.04	0.15	0.16	0.05	0.12
LSD(0.05)	M(NS)	D(NS)	M xD(NS)	M(NS)	D(NS)	M xD(NS)	M(NS)	D(NS)	M xD(NS)	
1	0.59	0.38	0.11	0.43	0.39	0.08	0.49	0.41	0.09	0.33
2	0.71	0.54	1.18	0.75	0.55	0.08	0.73	0.63	0.55	0.65
3	0.48	0.36	0.08	0.29	0.22	0.07	0.35	0.33	0.07	0.25
4	0.26	0.21	0.06	0.20	0.16	0.06	0.23	0.21	0.06	0.16
Mean	0.51	0.37	0.36	0.42	0.33	0.07	0.45	0.32	0.07	0.32
LSD(0.05)	M(NS)	D(NS)	M xD(NS)	M(0.30)	D(NS)	M xD(NS)	M(0.20)	D(NS)	M xD(NS)	
1	0.72	0.63	0.21	0.71	0.47	0.11	0.72	0.55	0.16	0.48
2	1.12	0.75	0.21	0.81	0.77	0.14	0.97	0.76	0.18	0.64
3	0.67	0.58	0.13	0.69	0.28	0.09	0.68	0.43	0.11	0.41
4	0.66	0.54	0.11	0.62	0.19	0.73	0.65	0.37	0.42	0.48
Mean	0.79	0.63	0.17	0.71	0.43	0.27	0.76	0.53	0.22	0.50
LSD(0.05)	M(0.06)	D(NS)	M xD(NS)	M(0.01)	D(NS)	M xD(NS)	M(0.09)	D(NS)	M xD(NS)	
1	1.27	0.78	0.24	1.53	0.88	0.27	1.40	0.83	0.26	0.83
2	1.30	0.80	0.36	2.09	0.96	0.47	1.70	0.88	0.42	1.00
3	0.96	0.70	0.24	0.99	0.59	0.18	0.98	0.65	0.21	0.61
4	0.84	0.62	0.24	1.09	0.34	0.14	0.97	0.48	0.19	0.55
Mean	1.09	0.73	0.27	1.43	0.69	0.27	1.26	0.71	0.27	0.75
LSD(0.05)	M(0.07)	D(NS)	M xD(NS)	M(0.44)	D(NS)	M xD(NS)	M(0.07)	D(NS)	M xD(NS)	

M: Month, D: Depth, M*D: Month*Depth, DAS: Days after sowing

4.5.2.1.1: Plant Height (cm):

The data presented in Table 4.17, at 60 days of seed sowing shows that maximum height of the seedling was in the month of March (31.52cm) and minimum was in the month of November (7.97cm). In the month of July, height was 25.87cm. Seedling height was influenced by time and depth of seed sowing through out the period of study. However, plant height in the month of March was significantly higher from the month of July and November. November was significantly lower than the month of March and July. Similarly, table indicates that, plant height was maximum at 2cm depth (24.51cm), followed by 1cm depth (22.19cm), 3cm depth (20.51cm) and minimum was at the depth of 4cm (19.93cm). Plant height at 4cm depth was significantly lower than 1 and 2cm depth. When we see the effect of depth

of sowing in different months, height at the depth of 2cm was found to be best in different months of sowing *i.e.* March (35.49cm) followed by July (29.41cm) and minimum plant height was in the month of November (8.63cm). Even in both the years, similar trend was also found in different months at different depths.

At the termination of study *i.e.* after four months (120 days) of seed sowing, maximum plant height of the seedling was in the month of March (48.11cm) and minimum was in the month of November (10.08cm). In the month of July, height was 37.24cm. Seedling height was influenced by time and depth of seed sowing throughout the period of study. However, plant height in the month of November was significantly lower than the month of March and July. Similarly, table (4.17) indicates that, plant height was maximum at 2cm depth (34.43cm), followed by 1cm depth (33.14cm), 3cm depth (31.12cm) and minimum was at the depth of 4 cm (28.55cm). Plant height at 4cm depth was significantly lower than 1 and 2cm depth. Plant height at depth 1, 2 and 3cm were statistically at par. When we see the effect of depth of sowing in different months, height at the depth of 2cm was found to be best in different months of sowing *i.e.* March (52.13cm) followed by July (40.34cm) and minimum plant height was in the month of November (10.82cm). Even in both the years, similar trend was also observed in various months at various depths. However, month of sowing continued to play major role in governing plant height.

Variation in plant height at fixed interval for different months of sowing may be attributed to the weather conditions during growth stage. In fact active growth was recorded from March to July. Therefore, seedlings enjoying growth period from March to July registered higher growth. Effect of sowing time on seed germination and seedling growth has been reported by several workers in Mango (Anonymous, 1985) and *Jatropha curcas* (Beniwal *et al*; 2004). Naidu and Swamy (1995) studied seasonal changes in the growth rate of seven tree species, and reported that growth rate showed monthly variation and variation between species. Similarly depth of seed sowing influences seedling growth on account of variation in seedling emergence.

Depth of seed sowing influences seed germination and seedling growth in *Casuarina equisetifolia* (Umarani *et al*; 1997). In Ber, Kajal and singhrot (1986) reported best growth at 2cm depth of sowing.

4.5.2.1.2 Collar diameter (cm):

Collar diameter of *Jatropha curcas* seedlings at monthly interval up to four month of age are presented in Table 4.17. The table indicates that effect of month and depth on collar diameter appears to be in accordance with plant height. Data reveals that at 60 days of seed sowing, maximum collar diameter of the seedling was in the month of March (0.86cm) and minimum in the month of November (0.69cm). In the month of July, collar diameter was 0.76cm. Collar diameter was influenced by time and depth of seed sowing through out the period of study. However, collar diameter in the month of November was significantly lower than the month of March and July. Similarly, table indicates that, collar diameter was maximum at 2cm depth (0.83cm), followed by 1cm depth (0.79cm), 3cm depth (0.75cm) and minimum was at the depth of 4cm (0.71cm).

Effect of various depth of sowing was found to be non significant for collar diameter. When we see the effect of depth of sowing in different months, collar diameter at the depth of 2cm was found to be best in different months of sowing *i.e.* March (0.94cm) followed by July (0.84cm) and minimum collar diameter was recorded in the month of November (0.72cm). Even in both the years, similar trend was found in various months and depths.

At the time of final observation (after four month of seed sowing), maximum collar diameter of the seedling was in the month of March (1.33cm) and minimum was in the month of November (0.87cm). In the month of July, height was 1.15cm. Collar diameter of the seedling was influenced by time and depth of seed sowing through out the period of study. However, collar diameter in the month of November was significantly lower than the month of March and July. Similarly, table (4.17) indicates that, collar diameter was maximum at 2cm depth (1.24cm), followed by

1cm depth (1.13cm), 3cm depth (1.07cm) and minimum was at the depth of 4 cm (1.02cm). Collar diameter at 4cm depth was significantly lower than 2cm depth. When we see the effect of depth of sowing in different months, collar diameter at the depth of 2cm was found to be best in different months of sowing *i.e.* March (1.58cm) followed by July (1.21cm) and minimum collar diameter was in the month of November (0.93cm). At this age appreciable improvement in collar diameter was recorded for the plants. Even in both the years, similar trend was also found in different months at different depths. Collar diameter of seedling reduced with increase in sowing depth. The species shows seasonal growth behaviour and slow growth and therefore, duration of growing season plays vital role in the growth of collar diameter. Seasonal variation in seedling growth of seven tree species has been documented (Naidu and Swamy, 1995). These results can be explained in light of prevailing weather conditions at the experimental site. The seedlings picked up higher collar diameter during active monsoon between March to July when the moisture and temperature are optimal for growth. Seeds sown after monsoon could not attain higher collar diameter because of unfavourable growing season. Similarly, those sown in March showed higher collar diameter during final observations on account of optimum growing season (July). Thus, it is apparent that time of seed sowing is the most important factor controlling plant growth.

4.5.2.1.3: Total dry weight (g):

A perusal of data indicated (Table 4.17) that initially, at the 60 days of seed sowing, maximum total dry weight of the seedling was in the month of March (3.23g) and minimum in the month of November (0.70g). In the month of July, total dry weight was 2.90g which was at par with month of March. Total dry weight was influenced by time and depth of seed sowing through out the period of study.

However, total dry weight in the month of November was significantly lower than the month of March and July. Similarly, table indicates that, total dry weight was maximum at 2cm depth (3.30g), followed by 1cm depth (2.51g), 3cm depth (2.01g)

and minimum was at the depth of 4cm (1.29g). Total dry weight at 4cm depth was significantly lower than other depths. When we see the effect of depth of sowing in different months, total dry weight at the depth of 2cm was found to be best in various months of sowing *i.e.* March (4.55g) followed by July (4.37g) and minimum total dry weight was found in the month of November (0.99g). Even in both the years, similar trend was also recorded in different months at various depths.

With further increase in age, total dry weight per plant showed marginal change. At the time of final observation (after four month of seed sowing), maximum total dry weight of the seedling was recorded in the month of March (3.89g) and minimum in the month of November (2.66g). In the month of July, total dry weight was 3.24g. Total dry weight was influenced by time and depth of seed sowing through out the period of study. However, total dry weight in the month of November was significantly lower than the month of March. Similarly, table indicates that, total dry weight was maximum at 2cm depth (3.45g), followed by 1cm depth (3.52g), 3cm depth (3.15g) and minimum was at the depth of 4cm (2.93g). Total dry weight at 4cm depth was significantly lower than other depths. When we see the effect of depth of sowing in different months, total dry weight at the depth of 2cm was found to be best in various months of sowing *i.e.* March (4.30g) followed by July (3.25g) and minimum total dry weight was found in the month of November (2.80g). Even in both the years, similar trend was also found in different months at various depths.

4.5.2.2: Growth analysis parameters:

In the process of under standing end results Relative Growth Rate, Net Assimilation Rate, Specific Leaf weight has marked influence on the final out come. In the present study these three parameters were studied and the results have been presented.

4.5.2.2.1: Relative Growth Rate (RGR) ($\text{g g}^{-1} \text{d}^{-1}$):

Relative Growth Rate of *Jatropha curcas* seedlings under the influence of time and depth of sowing on seedling growth was worked out at 30 days interval. The data has been presented in Table 4.17. At the termination of study, 90-120 days of interval, the results indicated that RGR values were maximum (0.023) RGR was registered in the month of March while closely followed by July (0.020) which was at par with month of March. Minimum (0.013) RGR was recorded in the month of November.

RGR was influenced by time and depth of seed sowing through out the period of study. However, RGR in the month of March was higher than the month of July and November. Similarly, table indicates that, RGR was maximum at 2cm depth (0.020), followed by 1cm depth (0.019), 3cm depth (0.018) and minimum (0.016) was at the depth of 4cm. 4cm depth was lower than respective depths. When we see the effect of depth of sowing in different months, RGR, at the depth of 2cm was found to be best in various months of sowing *i.e.* March (0.025) followed by July (0.021) and minimum (0.015) RGR was found in the month of November. In different months, RGR at 4cm depth was recorded minimum *i.e.* March (0.020) followed by July (0.018) and minimum (0.011) was found in the month of November. Similar trend was also recorded in different months at various depths.

RGR express the dry weight increase in a time interval in relation to the initial weight. Gardner *et al.* (1985) reported that RGR of crop plants generally begins slowly, peaks rapidly, soon afterward and than falls off. Species vary in RGR. In this experiment RGR values between 90-180 days were quite low and increased drastically between 180-270 days and dropped afterwards between 270-360 days.

4.5.2.2.2: Net Assimilation Rate (NAR) ($\text{mg cm}^{-2} \text{d}^{-1}$):

Net Assimilatory Rate of *Jatropha curcas* seedlings under the influence of time and depth of sowing on seedling growth was worked out at 30 days interval. The data has been presented in Table 4.17. At the time of final observation, 90-120 days of interval, it is apparent from the data that maximum (0.15) NAR was registered in the

month of March while closely followed by July (0.13) which was at par with month of March. Minimum (0.09) NAR was recorded in the month of November.

NAR was influenced by time and depth of seed sowing through out the period of study. However, NAR in the month of March was higher than the month of July and November. Similarly, table indicates that, NAR was maximum at 2cm depth (0.14), followed by 1cm depth (0.13), 3cm depth (0.12) and minimum (0.10) was at the depth of 4cm. 4cm depth was than respective depths. When we see the effect of depth of sowing in different months, NAR, at the depth of 2cm was found to be best in various months of sowing *i.e.* March (0.16) followed by July (0.14) and minimum (0.09) NAR was found in the month of November. In different months, NAR at 4cm depth was recorded minimum *i.e.* March (0.13) followed by July (0.11) and minimum (0.06) was found in the month of November. Similar trend was also recorded in different months at various depths.

NAR depicts net gain of assimilates per unit of leaf area and time. In general, NAR decreased with increasing level of shade though the trend was not consistent during 90-180 days. Hunt (1978) reported that NAR is not constant with time but shows an ontogenetic downward drift with plant age. Further, age drift was accelerated by unfavourable environment. Increased competition for nutrient and other factors are probably also important as age and size increases. The findings of Rao (1991) are in accordance with our findings, who recorded reduction in NAR, with increasing level of shade in *Acer oblongum* and *Olea glandulifera*.

4.5.2.2.3: Specific Leaf Weight (SLW) (mg cm^{-2}):

Specific leaf weight of *Jatropha curcas* seedlings at monthly interval up to four month of age for seeds sown in different months and depths was recorded and presented in Table 4.17. It is obvious from the data that SLW appears to be in accordance with plant height. Data reveals that, at 60 days of seed sowing, maximum SLW of the seedling was in the month of March (3.50) and minimum in the month of November (3.19). In the month of July, SLW was 3.04. SLW was influenced by time

and depth of seed sowing through out the study period. However, SLW in the month of November was lower than the month of March and July. Similarly, table indicates that, SLW was maximum at 2cm depth (3.80), followed by 1cm depth (3.27), 3cm depth (3.20) and minimum was at the depth of 4cm (2.70). SLW at depth 1cm and 3cm were statistically at par. When we see the effect of depth of sowing in different months, SLW at the depth of 2cm was found to be best in different months of sowing *i.e.* March (4.15) followed by July (3.85) and minimum SLW was in the month of November (3.40). Similar trend was also recorded in different months at various depths.

At the time of final observation (after four month of seed sowing), 120 days of seed sowing, maximum SLW of the seedling was in the month of March (3.88) and minimum was in the month of November (3.24). In the month of July, SLW was 2.55cm. SLW of the seedling was influenced by time and depth of seed sowing through out the period of study. However, SLW in the month of November was lower than the month of March and July. Similarly, table (4.17) indicates that, SLW was maximum at 2cm depth (3.65), followed by 1cm depth (3.52), 3cm depth (2.88) and minimum was at the depth of 4 cm (2.83). SLW at 4cm depth was lower than respective depth. When we see the effect of depth of sowing in different months, SLW at the depth of 2cm was found to be best in different months of sowing *i.e.* March (4.30) followed by July (3.75) and minimum SLW was in the month of November (2.90). At this age appreciable improvement in SLW was recorded for the plants. Similar trend was also found in different months at different depths. SLW of seedling reduced with increase in sowing depth. The species shows seasonal growth behaviour and slow growth and therefore, duration of growing season plays vital role in the growth of SLW.

4.5.2.2.4: Root: Shoot ratio:

Data pertaining to Root: shoot ratio has been presented in Table (4.17). Maximum root: shoot ratio of the seedling was recorded in the month of March (0.29)

followed by July (0.26) and minimum (0.24) root: shoot ratio was recorded in the month of November. Root shoot ratio was influenced by time and depth of seed sowing through out the study period. Similarly, table indicates that, root shoot ratio was maximum at 2cm depth (0.32), followed by 1cm depth (0.28), 3cm depth (0.26) and minimum was at the depth of 4cm (0.19). When we see the effect of depth of sowing in different months, root shoot ratio at the depth of 2cm was found to be best in various months of sowing *i.e.* March (0.35), July (0.30) and November (0.30). Similar trend was also found in different months at various depths and various months.

With the increase in age of seedling at four months (120 days) of age, maximum root: shoot ratio of the seedling was in the month of March (0.25) and minimum (0.21) root: shoot ratio was recorded in the month of November and July. Root shoot ratio was influenced by time and depth of seed sowing through out the study period. Similarly, table indicates that, root shoot ratio was maximum at 2cm depth (0.24), followed by 1cm and 3cm depth (0.22), and minimum was at the depth of 4cm (0.21). When we see the effect of depth of sowing in different months, root shoot ratio at the depth of 2cm was found to be best in various months of sowing *i.e.* March (0.27), July (0.22) and November (0.22). Similar trend was also found in different months at various depths and various months in both the years.

4.5.2.2.5: Partitioning of Biomass yield (g):

Biomass yield (g) was recorded at 30 days interval up to four month after seed sowing and it was partitioned into above ground and below ground biomass and presented in terms of dry biomass yield (Table 4.17).

4.5.2.2.5.1: Above ground biomass (g):

Data pertaining to above ground biomass has been presented in Table (4.17). Perusal of data shows that at the 60 days of seed sowing, maximum above ground biomass of the seedling was in the month of March (2.86g) followed by July (2.53g)

and minimum (0.60g) above ground biomass was recorded in the month of November. Above ground biomass in November was significantly lower than the month of March and July. Above ground biomass was influenced by time and depth of seed sowing through out the study period. Similarly, table indicates that, above ground biomass was maximum at 2cm depth (4.54g), followed by 1cm depth (3.39g), 3cm depth (2.91g) and minimum was at the depth of 4cm (2.47g). Above ground biomass yield showed decreasing trend with increasing depth of sowing after 2cm. 2cm depth was significantly higher than other depths. When we see the effect of depth of sowing in different months, above ground biomass at the depth of 2cm was found to be best in various months of sowing *i.e.* March (4.04g) followed by July (3.84g) and minimum (0.80g) above ground biomass was recorded in the month of November. Similar trend was also found in different months at various depths and various months.

With the increase in age of seedling at four months (120 days) age, data reveals that maximum above ground biomass of the seedling was in the month of March (9.20g) followed by July (5.01g) and minimum (1.50g) above ground biomass was recorded in the month of November. Above ground biomass in the month of November was significantly lower than March and July. Similarly, table indicates that above ground biomass was maximum at 2cm depth (6.96g), followed by 1cm depth (5.62g), 3cm depth (4.63g) and minimum (3.74g) was at the depth of 4cm. 1cm and 2cm depth was significantly higher than 3cm and 4cm depths. When we see the effect of depth of sowing in different months, above ground biomass at the depth of 2cm was found to be best in various months of sowing *i.e.* March (12.33g) followed by July (6.56g) and minimum (1.99g) above ground biomass was recorded in the month of November. Similar trend was also found in different months at various depths and various months.

4.5.2.2.5.2: Below ground biomass:

Below ground biomass was recorded and presented in Table 4.17. Statistical analysis of data revealed that influences of time and depth of sowing on below ground biomass. At the 60 days of seed sowing, maximum (0.45g) below ground biomass was recorded in the month of March, followed by July (0.32g) and minimum (0.07g) was recorded in the month of November. Below ground biomass in November was significantly lower than the month of March and July. Sowing at 2cm depth (0.65g) was higher than rest of the treatments. Below ground biomass decreased with increase in sowing depth after 2cm depth. Minimum below ground biomass (0.16g) was recorded in seedling sown at 4cm depth, which was lower than rest of the treatments at respective depths. Below ground biomass at the depth of 2cm was found to be best in various months of sowing *i.e.* March (0.73g) followed by July (0.63g) and minimum (0.55g) below ground biomass was recorded in the month of November. Similar trend was also found in different months at various depths and various months.

With the increase in age of seedling at 120 days, data reveals that maximum below ground biomass of the seedling was in the month of March (1.26g) followed by July (0.71g) and minimum (0.27g) below ground biomass in the month of November. Below ground biomass in November was significantly lower than the month of March and July. Below ground biomass was influenced by time and depth of seed sowing through out the study period. Similarly, table indicates that, below ground biomass was maximum at 2cm depth (1.00g), followed by 1cm depth (0.83g), 3cm depth (0.61g) and minimum (0.55g) was at the depth of 4cm. When we see the effect of depth of sowing in different months, below ground biomass at the depth of 2cm was found to be best in various months of sowing *i.e.* March (1.70g) followed by July (0.88g) and minimum (0.42g) below ground biomass was recorded in the month of November. Similar trend was also found in different months at various depths and various months.

A critical perusal of data shows that above ground biomass, in general was recorded higher than below ground biomass. In Ber, Kajal and Singhrot (1986) reported best growth at 2cm depth of sowing. Mutha *et al.* (1995) studied that *P. juliflora* seed at about 10mm depth gave seedling of high sturdiness quotient. Deep sowing on the contrary resulted in the poor seedling quality. Shoot dry weight showed decreasing trend with increasing depth of sowing the difference between all the values were non-significant. In spite of root length was almost similar to shoot length the root dry weight is very low than shoot dry weight. This may be attributed to deep tap root system of the species. Bedell *et al.* (1993) opined that in arid lands root elongation is rapid than that of shoot. Arjunan *et al.* (1994) studied the effect of seed size and sowing depth on seed germination and seedling growth of *P. pinnata* and reported that larger seed produced higher biomass production at 1cm depth of sowing. Present study showed that shoot dry weight was maximum at 1cm depth, whereas, root dry weight was found maximum at 2cm depth of sowing. Depth of seed sowing influences seed germination and seedling growth in *Casuarina equisetifolia* (Umarani *et al.*, 1997). This may be attributed to the fact that roots tend to grow deeper in search of moisture and nutrients and helps the plant to survive against drought and biotic pressure. Tewari *et al.* (2000) reported 16cm annual increment in plant height and 0.51cm in collar diameter during initial 3 years of plant growth.

They further reported that root length is approximately 3 times, the shoot length in nursery. Reduction in above ground and below ground biomass at increasing depth of sowing is due to late emergence of seedling affecting availability of total span of congenial growing conditions. The seedling which experienced longer growing period (monsoon season) accumulated higher biomass. Seeds sown November had minimum active growing period by the age of four month, hence recorded minimum biomass yield, where as the seeds sown in March experienced longer active growing period, thus had maximum biomass.

4.6: Effect of shade on seed germination and seedling growth:

The experiment was conducted to study the effect of different shade levels *i.e.* 35, 50 and 75 percent along with control on seed germination behaviour and seedling growth. The experiment was conducted under field conditions. The results are presented below.

4.6.1: Germination Response:

4.6.1.1: Initiation and completion of germination and germination percent:

Observations on germination per cent, initiation and completion of germination were recorded and presented in Table 4.18. The influence of light intensity has a great significance on the seed germination and growth of seedlings, as it is the only source of energy which is fixed by them in the form of chemical energy by photosynthetic carbon assimilation for use in various life processes. Many plant species are shade loving or light demanding during their early phase of life. It is apparent from the data that the germination percent was highest at 35% shade level (70%) and it was followed by control (58.34%), 50% shade level (51.67%) and minimum (41.67%) at 75% shade level was recorded. Here we see that heavy shade reduced the germination percent drastically. Even in both the years 35% shade level was found to be best in comparison to control and shade level of 50% and 75%. The table clearly indicates that with the increase in shade level, initiation of germination was delayed. However, various shade levels did not significantly influence days taken to initiate germination. Heavy shade (75%) registered maximum (8.00) days to initiate germination, while minimum (6.17) days taken to initiate germination was under 35% shade and it was followed by control (7.00). Days taken to initiate germination in 50% shade level were 7.33 days. Even in both the years, minimum days taken to initiate germination was under 35% shade level and heavy shade (75%) registered maximum days to initiate germination.

From present study, it can be concluded that light intensity affect the days taken to initiate and complete germination in *Jatropha curcas*. Days taken to initiate and complete germination increased with increasing shade level. Shade level of 35% was good for seed germination in *Jatropha curcas*. It may be attributed that seed required light to regulate the process of seed germination.

Data on days taken to complete germination indicated that seeds sown at 75% shade level recorded maximum (15.17) days to complete germination followed by 50% shade (12.84) days. Minimum (10.50) days were taken to complete germination under 35% shed and in control (12.17) days were taken. Days taken to complete germination at 35% shade level were significantly lower than other shade levels. Even in both the years, minimum days taken to complete germination were under 35% shade level and heavy shade (75%) registered maximum days to complete germination.

Table 4.18: Effect of different levels of shade on initiation and completion of germination and germination percentage, in *Jatropha curcas* seeds and seedling growth

Shade levels (%)	Parameters								
	Initiation of germination (days)			Completion of germination (days)			Germination (%)		
	2005	2006	Pooled mean	2005	2006	Pooled mean	2005	2006	Pooled mean
35	5.67	6.67	6.17	11.00	10.00	10.50	73.33	66.67	70.00
50	7.33	7.33	7.33	13.00	12.67	12.84	46.67	56.67	51.67
75	8.33	7.67	8.00	15.67	14.67	15.17	40.00	43.33	41.67
Control	7.00	7.00	7.00	12.67	11.67	12.17	56.67	60.00	58.34
LSD (0.05)	NS	NS	NS	NS	0.69	1.43	10.28	NS	NS

From present study, it is obvious that *Jatropha* seeds take 6.17 to 8.00 days to initiate and 10.50-15.17 days to complete germination. Longer period to initiate germination is obviously due to hard seed coat. It appears that shade does not effect days taken to initiate and complete germination in *Jatropha*. It is stony endocarp,

which determines days taken to initiate and complete germination on account of imbibitions of water.

4.6.2: Growth performance:

Growth observations at various shade levels (35, 50, 75% and control 0% shade) were recorded at monthly interval up to four months in terms of plant height, collar diameter, Total dry weight, Root: Shoot ratio, Net Assimilatory rate, Relative Growth Rate, Specific Leaf weight and Height: Stem dry weight.

Shade effect on growth parameters was significant for plant height and collar diameter for 60, 90 and 120 days. All the data have been presented in Table 4.19 at different days of observations.

4.6.2.1: Plant Height (cm):

The data in Table 4.19 reveals that at 60 days of seed sowing, maximum height of the seedling was registered (30.29cm) at 50% shade level, followed by 35% shade level (27.43cm) at and minimum was recorded at 75% shade level (23.61cm). In control, height was recorded 24.67cm. Seedling height was influenced by various shade levels through out the period of study. However, plant height at 75% shade level was significantly lower than 35 and 50% shade levels. When we see the effect of shade levels, plant height at 50% shade level was found to be best in different shade levels. Similar trend was also found in different days of seed sowing.

At the termination of study *i.e.* after four months (120 days) of seed sowing, maximum plant height of the seedling was registered (44.56cm) at 50% shade level, followed by 35% shade level (44.02cm) and minimum plant height (35.79cm) was recorded at 75% shade level. In control, plant height was 37.11cm. Seedling height was influenced by shade levels through out the period of study. However, plant height at 75% shade level was significantly lower than 35 and 50% shade levels. When we see the effect of shade levels, plant height at 50% shade level was found to be best in different shade levels. Similar trend was also found in different days of

seed sowing. However, month of sowing continued to play major role in governing plant height.

Variation in plant height at fixed interval for different shade levels of sowing may be attributed to the weather conditions during growth stage. In fact active growth was recorded from 35 to 50% shade levels.

4.6.2.2: Collar diameter (cm):

Collar diameter of *Jatropha curcas* seedlings at monthly interval up to four month of age for seeds sown in different shade levels was recorded and presented in Table 4.19. It is obvious from the data that collar diameter appears to be in accordance with plant height. Data reveals that, at 60 days of seed sowing, maximum collar diameter of the seedling was registered (0.99cm) at 50% shade level, followed by) at 35% shade level (0.91cm) and minimum collar diameter (0.83cm) was recorded at 75% shade level. In control, collar diameter was 0.87cm. Collar diameter of the seedling was influenced by shade levels through out the period of study. However, collar diameter at 75% shade level was significantly lower than 50% shade levels. When we see the effect of shade levels, collar diameter at 50% shade level was found to be best in different shade levels. Similar trend was also found in different days of seed sowing.

At the time of final observations *i.e.* after four months (120 days) of seed sowing, maximum plant height of the seedling was registered (1.55cm) at 50% shade level, followed by at 35% shade level (1.49cm) and minimum was recorded (1.19cm) at 75% shade level. In control, collar diameter was 1.25cm.

Table-4.19: Effect of different levels of shade on different growth parameters in *Jatropha curcas*

Shade levels (%)	DAS	2005				2006				Mean							
		35	50	75	LSD (0.05)	Control	LSD (0.05)	35	50	75	Control	LSD (0.05)					
PH	30	17.08	18.36	14.35	NS	16.69	NS	19.96	21.01	15.40	18.38	2.41	18.52	19.69	14.88	17.54	NS
	60	25.56	26.31	21.99	NS	23.28	NS	29.29	34.27	25.23	26.06	2.55	27.43	30.29	23.61	24.67	1.89
	90	31.83	32.93	25.85	NS	31.50	NS	37.22	40.41	2.74	32.22	NS	34.53	36.67	14.30	31.86	4.49
	120	40.25	41.08	33.50	4.03	33.78	4.03	47.78	48.04	38.08	40.44	3.88	44.02	44.56	35.79	37.11	3.85
CD	30	0.66	0.70	0.64	NS	0.67	NS	0.72	0.78	0.65	0.67	0.06	0.69	0.74	0.65	0.67	NS
	60	0.86	0.89	0.78	NS	0.79	NS	0.96	1.09	0.87	0.94	0.08	0.91	0.99	0.83	0.87	0.09
	90	1.03	1.07	0.94	NS	1.00	NS	1.15	1.46	1.04	1.13	0.17	1.09	1.27	0.99	1.07	0.16
	120	1.21	1.30	1.17	NS	1.20	NS	1.77	1.80	1.21	1.30	NS	1.49	1.55	1.19	1.25	0.25
TDW	30	1.05	1.11	0.68	NS	0.86	NS	1.79	1.80	0.71	1.25	NS	1.42	1.46	0.70	1.06	NS
	60	1.92	2.21	1.08	NS	1.89	NS	2.24	2.89	2.10	2.40	NS	2.08	2.55	1.59	2.15	0.59
	90	4.06	4.46	3.21	NS	3.98	NS	4.81	5.52	3.59	4.23	NS	4.40	4.99	3.40	4.11	NS
	120	10.45	11.07	5.30	1.43	5.53	1.43	10.70	13.87	6.32	7.63	NS	10.58	12.47	5.81	6.58	3.62
RGR	30-60	0.031	0.032	0.016	-	0.030	-	0.024	0.039	0.023	0.025	-	0.028	0.036	0.020	0.028	-
	60-90	0.036	0.038	0.030	-	0.036	-	0.020	0.022	0.020	0.020	-	0.028	0.03	0.025	0.028	-
	90-120	0.032	0.033	0.012	-	0.031	-	0.031	0.032	0.019	0.027	-	0.032	0.033	0.016	0.029	-
	30-60	0.20	0.32	0.17	-	0.30	-	0.16	0.24	0.14	0.15	-	0.18	0.28	0.16	0.23	-
NAR	60-90	0.30	0.50	0.28	-	0.29	-	0.15	0.16	0.10	0.12	-	0.23	0.33	0.18	0.21	-
	90-120	0.27	0.28	0.15	-	0.25	-	0.22	0.29	0.11	0.13	-	0.25	0.29	0.13	0.19	-
	30	5.10	6.00	4.80	-	4.90	-	5.50	8.70	3.10	5.50	-	5.30	7.35	3.95	5.20	-
	60	4.60	13.40	4.50	-	4.60	-	3.20	3.50	2.40	2.50	-	3.90	8.45	3.45	3.55	-
SLW	90	6.10	6.20	3.15	-	3.40	-	3.00	3.14	2.50	2.59	-	4.55	4.67	2.83	2.99	-
	120	3.80	3.97	3.22	-	3.80	-	3.80	3.90	2.40	3.70	-	3.80	3.94	2.81	3.75	-
	30	0.25	1.08	0.19	NS	0.22	NS	1.40	1.80	0.68	0.89	NS	0.825	1.44	0.44	0.56	NS
	60	0.23	0.66	0.17	NS	0.20	NS	0.27	0.30	0.16	0.24	NS	0.25	0.48	0.17	0.22	NS
R:S ratio	90	0.21	0.22	0.17	NS	0.18	NS	0.24	0.28	0.14	0.22	NS	0.225	0.25	0.16	0.20	NS
	120	0.22	0.26	0.17	NS	0.20	NS	0.22	0.26	0.17	0.20	NS	0.22	0.26	0.17	0.20	NS
	30	62.30	72.90	55.78	NS	62.20	NS	61.71	62.68	37.33	45.72	NS	62.01	67.79	46.56	53.96	NS
	60	46.15	48.52	26.71	NS	31.89	NS	38.58	40.46	24.64	26.70	NS	42.37	44.49	25.68	29.30	NS
H:S dry wt	90	18.61	21.38	14.60	NS	16.07	NS	22.22	28.55	16.74	17.43	5.25	20.415	24.97	15.67	16.75	NS
	120	16.00	18.57	7.34	5.91	8.15	5.91	12.24	18.42	8.39	11.36	NS	14.12	18.50	7.87	9.76	6.70

DAS: Days after sowing, PH: Plant height (cm), CD: Collar diameter (cm), TDW: Total dry weight (g), R: S ratio: Root: Shoot ratio, NAR: Net Assimilatory Rate (mg cm⁻² d⁻¹), RGR: Relative Growth Rate (g g⁻¹ d⁻¹), SLW: Specific Leaf weight (mg cm⁻²), H: S dry wt.: Height: Stem dry weight (cm g⁻¹)

Collar diameter was influenced by shade levels through out the period of study. However, collar diameter at 75% shade level was significantly lower than 35 and 50% shade levels. The effect of shade levels, plant height at 50% shade level was found to be best in different shade levels. Similar trend was also found in different days of seed sowing.

At this age appreciable improvement in collar diameter was recorded for the plants. Similar trend was also found in different months at different depths. The species shows seasonal growth behaviour and slow growth and therefore, duration of growing season plays vital role in the growth of collar diameter.

4.6.2.3: Total dry weight (g):

A perusal of data indicated (Table 4.19) that initially, at the 60 days of seed sowing, maximum total dry weight of the seedling was registered (2.55g) at 50% shade level, followed by 2.08g at 35% shade level and minimum (1.59g) was at 75% shade level. In control, total dry weight recorded was 2.15g. Total dry weight of the seedling was influenced by shade levels through out the period of study. However, total dry weight at 75% shade level was significantly lower than 50% shade levels. When we see the effect of shade levels, total dry weight at 50% shade level was found to be best in different shade levels. Similar trend was also found in different days of seed sowing.

With further increase in age, Total dry weight per plant showed marginal change. At the time of final observations *i.e.* after four months (120 days) of seed sowing, maximum total dry weight of the seedling (12.47g) was registered at 50% shade level, followed by (10.58g) at 35% shade level and minimum was (5.81) at 75% shade level. In control, total dry weight was recorded 6.58g. Total dry weight of seedling was influenced by shade levels through out the growing period. However, total dry weight at 75% shade level was significantly lower than 35 and 50% shade levels. Total dry weight at 50% shade level was found to be best in different shade levels. Similar trend was also found in different days of seed sowing.

4.6.3: Growth analysis parameters:

Relative Growth Rate, Net Assimilation Rate, Specific Leaf weight has marked influence on the final outcome. In the present study these three parameters were studied and the results have been presented.

4.6.3.1: Relative Growth Rate (RGR) ($\text{g g}^{-1} \text{d}^{-1}$):

Relative Growth Rate of *Jatropha curcas* seedlings under the influence of different types of shade levels on seedling growth was worked out at 30 days interval. The data has been presented in Table 4.19. At the termination of study, 90-120 days of interval, the results indicated that RGR values were maximum (0.033) at 50% shade level which was higher than different types of shade levels, while was closely followed by RGR at 35% shade level (0.020). Minimum RGR was recorded at 75% shade level (0.016). RGR in Control was 0.029. Similar trend was also recorded in different shade levels.

RGR express the dry weight increase in a time interval in relation to the initial weight. Gardner *et al.* (1985) reported that RGR of crop plants generally begins slowly, peaks rapidly, soon afterward and then falls off. Species vary in RGR. In this experiment RGR values between 90-120 days were relatively high in comparison to 30-60 and 60-90 days. The effect of shade on RGR did not show any definite trend during the course of investigation, however, mean values of RGR, showed reduction under heavy shade (75%). Similar observations have been reported in *Quercus floribunda* and *Cupressus torulosa* by Rao, (1988).

4.6.3.2: Net Assimilation Rate (NAR) ($\text{mg cm}^{-2} \text{d}^{-1}$):

Net Assimilatory Rate of *Jatropha curcas* seedlings under the influence of different types of shade levels on seedling growth was worked out at 30 days interval. The data has been presented in Table 4.19. At the time of final observation, 90-120 days of interval, it is apparent from the data that maximum NAR (0.29) was registered at 50% shade level which was higher than various other types of shade

levels, which was closely followed by at 35% shade level (0.25). Minimum NAR (0.13) was recorded at 75% shade level. NAR in Control was 0.19. NAR was influenced by different types of shade levels through out the growing period. Similar trend was also recorded in different shade levels.

NAR depicts net gain of assimilates per unit of leaf area and time. Hunt (1978) reported that NAR is not constant with time but shows an ontogenetic downward drift with plant age. Further, age drift was accelerated by unfavourable environment. Increased competition for nutrient and other factors are probably also important as age and size increases. The findings of Rao (1991) are in accordance with our findings, who recorded reduction in NAR, with increasing level of shade in *Acer oblongum* and *Olea glandulifera*.

4.6.3.3: Specific leaf weight (SLW) (mg cm^{-2}):

Specific leaf weight of *Jatropha curcas* seedlings at monthly interval up to four month of age for seeds sown in different shade levels was recorded and presented in Table 4.19. It is obvious from the data that SLW appears to be in accordance with plant height. Data reveals that, at 60 days of seed sowing, maximum SLW (8.45) of the seedling was at 50% shade level which was higher than various other shade levels, followed by at 35% shade level (3.90) and minimum SLW (3.45) was recorded at 75% shade level. In control, SLW recorded was 3.55. SLW was influenced by various types of shade levels through out the study period.

At the time of final observation (after 120 days of seed sowing), maximum SLW of the seedling was 3.94 at 50% shade level which was higher than various types of shade levels, followed by at 35% shade level (3.80) and minimum SLW (2.81) was recorded at 75% shade level. In control SLW recorded was 3.75. Similar trend was also recorded at various shade levels.

SLW of seedling reduced with increase in shade levels. The species shows seasonal growth behaviour and slow growth and therefore, duration of growing season plays vital role in the growth of SLW.

4.6.3.4: Root: Shoot ratio:

Data pertaining to root: shoot ratio has been presented in Table (4.19). At the 60 days of seed sowing, maximum root shoot ratio of the seedling was 0.48 at 50% shade level which was higher than other shade levels, followed by at 35% shade level (0.25) and minimum (0.17) root shoot ratio was recorded at 75% shade level. In control root shoot ratio was 0.22. Root shoot ratio was influenced by various types of shade levels while 50% shade level recorded high root: shoot ratio throughout the study period. Similar trend was also recorded at various shade levels.

With the increase in age of seedling (at 120 days), the data indicated that maximum root: shoot ratio of the seedling was 0.26 at 50% shade level which was higher than various shade levels, followed by at 35% shade level 0.22 and minimum (0.17) root shoot ratio was recorded at 75% shade level. In control root shoot ratio was 0.20. Even in both the years, 50% shade level was found to be best in comparison to other shade levels. Similar trend was also recorded at various shade levels.

Shade plays vital role in regeneration and growth of plants under natural habitat. *Jatropha curcas* is a common associate of mixed dry deciduous forest, hence experiences shade during germination and growth. Peer *et al.* (1998) reported that certain plants tolerate shade through shade tolerance mechanism, which is inheritable character.

Gansert and Sprike (1998), while studying storage and mobilization of non-structural CHO and biomass development under different light intensities in *Fagus sylvatica* reported that plant survives under limited light by way of shift in shoot growth during 1st half of growing season, and suppression of lateral shoot growth, during 2nd half of growing season. Starch concentration in roots decreased with reduction in light intensity and lateral root growth also reduced. In the present study it was observed that increasing shade intensity favored plant height, collar diameter and leaf area. Our findings are in accordance with the findings of Mazzei *et al.* (1998), who reported that the seedlings subjected to 0% shade had the smallest averages for

all the parameters studied, except root-shoot ratio, which was smallest under 90% shade level. Similarly, Saxena *et al.* (1995) reported that production of height and stem diameter, per unit dry weight higher under shade for *Dalbergia sissoo*, *Acacia catechu* and *Casuarina equisetifolia*.

Salgado *et al.* (1998) reported that shading favoured height of *Zanthoxylum rhoifolium*. On the contrary, Naidu and Swamy (1993) reported that *Pongamia pinnata* grown under shade showed a decrease in root and shoot growth while leaf area increased. Welander and Ottoson (1998) opined that shade effect may be reflected in same season or next season also. Therefore, the species susceptible to low light availability may need additional light in subsequent growth season for survival and growth. Treatments showed non-significant variations among themselves. Loach (1970), suggested that the capacity to maximize dry matter production in shade through reduction in root: shoot is most apparent in competitive species characteristic of unshaded or lightly shaded environment; while shade tolerant species tend to show little morphogenetic response to shade treatment. Osmond *et al.* (1980) suggested that the reduced root growth may not have any significant disadvantage in shaded habitat.

Rao *et al.* (1987) reported that deep shade caused marked decrease in root shoot ratio of *A. indica*. The species has an ability to endure the shade as well as to grow well in forest. Similarly, Rao and Singh (1989) reported that deep shade caused a marked decrease in root: shoot ratio of late successional trees. The findings of present investigation are in conformity with the above reports. Reduction in root: shoot ratio with increasing level of shade indicates that more photosynthates accumulated above ground parts at higher shade level. Kuo and Huang (1998) reported that energy use efficiency of *Michelia compressa* was maximum under 12% light treatment and minimum under 81% light.

Further, Negi *et al.* (1994) reported that *Pinus patula* seedlings recorded higher root shoot: ratio at intermediate shade level. However, Chen (1997) reported that expressions of morphological characters in different shade tolerant tree species

vary greatly and more tolerant tree show greater plasticity in morphological characters than less tolerant species.

4.6.3.5: Height: Stem dry weight (cm g^{-1}):

Data on Height: Stem dry weight of *Jatropha curcas* seedlings at monthly interval as influenced by different types of shade levels have been presented in Table 4.19. At 60 days of seed sowing, the differences among various shade levels were non significant. Maximum Height: Stem dry weight of the seedling was 44.49 at 50% shade level which was higher than various shade levels, followed by at 35% shade level 42.37 and minimum Height: Stem dry weight (25.68) was recorded at 75% shade level. In control Height: Stem dry weight was 29.30. Height: Stem dry weight was influenced by various types of shade levels through out the study period. Similar trend was also recorded at various shade levels. A treatment shows non-significant effects.

With the increase in age of seedling at four months age, the data indicated that maximum Height: Stem dry weight of the seedling was 18.50 at 50% shade level which was higher than other shade levels, followed by at 35% shade level 14.19 and minimum Height: Stem dry weight (7.87) was recorded at 75% shade level. In control Height: Stem dry weight was 9.76. 50% shade level was significantly higher than 75% shade level. Height: Stem dry weight was influenced by various types of shade levels through out the study period. Even in both the years, 50% shade level was found to be best in comparison to other shade levels. Similar trend was also recorded at various shade levels.

Under natural habitat plants are often exposed to various degree of shade. Shade not only effect plant growth but also influence dry matter accumulation in different plant part. Grime (1981) has given evidence for existence of three primary strategies in plants, viz; competitive strategy, ruderal strategy and tolerant strategy to stress and considered shade a major criterion for differentiating species from the standpoint of the above three adoptational strategies. It is anticipated that organism

may exhibit quite different strategies during juvenile and established phases of their life cycle. On the contrary, Puri and swami (2001) reported that neem seedlings grown in complete light had four times more biomass than those grown under diffused light. In the present investigation, it was observed that total biomass production increased with increase in shade level up to 75%.

A partitioning of total biomass into root and shoot revealed that biomass accumulation in below ground plant part (root) decreased with increase in degree of shade. Though, the effect of shade on below ground biomass was not significant under various shade treatments. Since, the species under goes dormancy by shedding leaves from March to May, the above ground growth ceases. However, roots continue to grow and accumulate biomass. This phenomenon explains reduction in above ground biomass observed during the course of present investigation. Kuo and Huang (1998), while studying effect of shade on growth of *Michelia compressa* reported that 81% sun light produced maximum biomass yield. However, energy use efficiency was maximum under 12% light treatment.

Wen Dazhi (1999) reported that broad leaved species viz; *Castanopsis fissa*, *Schima superba* and *Cryptocarya concinna* showed more growth under shade than full sun light. Increase in biomass under increasing shade may be justified in light of observations on number of leaves and leaf area/plant, which showed increasing trend with shade.

4.7: Studies on comparison of growth performance of poly bag and seedbed grown seedlings of *Jatropha curcas*:

4.7.1: Days taken to initiate and complete germination and germination percent:

The result of germination percentage and the days taken to initiate and complete germination as influenced by polythene bag and nursery bed have been summarized in Table.4.20.

Days taken to initiate germination were recorded minimum in polythene bag (7.34 days) in comparison to nursery bed (7.63 days) in different soil mixtures. In polythene bag, days taken to initiate germination was minimum (6.67days) with S+B+FYM mixture followed by R+B+FYM mixture (7.17 days), R+FYM mixture (7.50 days) while maximum days was taken with B+FYM mixture (8.00 days). Days taken to initiate germination with S+B+FYM mixture was significantly lower than R+FYM and B+FYM mixture. Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed.

Days taken to complete germination were recorded minimum in polythene bag (12.30days) in comparison to nursery bed (13.71days) in different soil mixtures. In polythene bag, days taken to complete germination was minimum (10.84days) with S+B+FYM mixture followed by R+B+FYM mixture (11.67days), R+FYM mixture (13.17days) while maximum days was taken with B+FYM mixture (13.50days) which was higher than different soil mixtures. Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed.

Germination percentage was recorded highest in poly bag (79.59%) in comparison to nursery bed (70.42%) in different soil mixtures. In polythene bag, maximum germination percentage (88.34%) was with S+B+FYM mixture followed by R+B+FYM mixture (83.33%), R+FYM mixture (73.34%) while minimum germination percentage (73.33%) was recorded with B+FYM mixture. Germination percentage with S+ B+FYM mixture was significantly higher than B+FYM and R+FYM mixture. Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed. Raising seedlings of tree species in nursery is a common phenomenon all over the world in present day plantation programme of agroforestry and forestry. The findings of present study showed that polythene bag is suitable for the fast germination of the seeds of *Jatropha curcas*. However, there was no more difference in between nursery bed and polythene bag grown seeds.

Josaiah and Jones (1992) have favoured root trainer technology for raising plants in forest nurseries. Seed sown in open nursery bed took maximum time to

initiate and complete seed germination. It may be attributed to the fact that the polythene bag and nursery bed has proper amount of potting mixture which favoured the seed germination.

Table: 4.20: Effect of different soil mixtures on initiation, completion of germination and germination percentage in *Jatropha curcas*

Soil mixtures	2005		2006		Mean	
	Nursery bed	Polythene bag	Nursery bed	Polythene bag	Nursery bed	Polythene bag
Initiation of germination (days)						
B+FYM	7.00	6.67	9.67	9.33	8.34	8.00
R+FYM	6.33	6.00	9.33	9.00	7.83	7.50
R+B+FYM	6.00	5.67	9.00	8.67	7.50	7.17
S+B+FYM	5.33	5.33	8.33	8.00	6.83	6.67
Mean	6.17	5.92	9.08	8.75	7.63	7.34
LSD (0.05)	NS	NS	NS	0.75	NS	0.78
Completion of germination (days)						
B+FYM	15.33	12.00	16.00	15.00	15.67	13.50
R+FYM	13.00	11.67	15.00	14.67	14.00	13.17
R+B+FYM	12.33	9.67	14.33	13.67	13.33	11.67
S+B+FYM	10.00	8.67	13.67	13.00	11.84	10.84
Mean	12.67	10.50	14.75	14.09	13.71	12.30
LSD (0.05)	NS	NS	NS	NS	2.43	NS
Germination (%)						
B+FYM	53.33	73.33	66.67	73.33	60.00	73.33
R+FYM	63.33	76.67	73.33	70.00	68.33	73.34
R+B+FYM	70.00	80.00	76.67	86.67	73.34	83.33
S+B+FYM	80.00	83.33	80.00	93.33	80.00	88.34
Mean	66.67	78.33	74.17	80.83	70.42	79.59
LSD (0.05)	NS	NS	NS	NS	NS	9.13

DAS: Days after sowing, B+FYM: Black soil + Farm Yard Manure, R+FYM: Red soil + Farm yard manure, R+B+FYM: Red soil+ Black soil + Farm Yard Manure, S+B+FYM: Sand + Black soil Farm Yard Manure

Findings of present study showed that all the germination parameters observed maximum in plastic bag grown seeds. Amidon *et al.* (1982) reported that under drought conditions container grown seedling survived better than nursery stock.

4.7.2: Growth performance:

Growth observations at various soil mixtures (B+FYM, R+FYM, R+B+FYM and S+B+FYM) with nursery bed and polythene bag were recorded at monthly

interval up to four months in terms of plant height, collar diameter, Total dry weight, Root: Shoot ratio, Net Assimilatory rate, Relative Growth Rate, Specific Leaf weight and Height: Stem dry weight.

All the data have been presented in Table 4.21 at different days of observations.

4.7.2.1: Plant Height (cm):

The data presented in Table 4.21 indicates that at 60 days of seed sowing maximum height of the seedling was registered in poly bag (30.67cm) in comparison to nursery bed (26.28cm) in different soil mixtures. In polythene bag, maximum plant height was with S+B+FYM mixture (35.81cm) followed by R+B+FYM mixture (31.33cm), R+FYM mixture (30.04cm) while minimum plant height (25.48cm) was recorded with B+FYM mixture. Plant height with S+ B+FYM mixture was significantly higher than B+FYM mixture. Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed in polythene bag and nursery bed with different soil mixtures.

At the termination of study *i.e.* after four months (120 days) of seed sowing, maximum plant height of the seedling was registered in polythene bag (46.14cm) in comparison to nursery bed (41.12cm) in different soil mixtures. In poly bag, maximum plant height was recorded with S+B+FYM mixture (50.87cm) followed by R+B+FYM mixture (47.58cm), R+FYM mixture (43.39cm) while minimum plant height was recorded with B+FYM soil mixture (42.70cm). Plant height with S+ B+FYM mixture was significantly higher than B+FYM and R+FYM soil mixture. Same trend was observed in nursery bed condition. When we see the effect of different soil mixtures in nursery bed and polythene bag, plant height at S+B+FYM soil mixture was found to be best. Even in both the years, similar trend was found.

Variation in plant height at fixed interval for different soil mixtures of sowing may be attributed to the weather conditions during growth stage. In fact active growth was recorded from S+B+FYM and R+B+FYM soil mixtures.

4.7.2.2: Collar diameter (cm):

Collar diameter of *Jatropha curcas* seedlings at monthly interval up to four month of age were recorded and presented in Table 4.21. Data reveals that at 60 days of seed sowing, maximum collar diameter of the seedling was registered in polythene bag (0.83cm) in comparison to nursery bed (0.78cm) in different soil mixtures. In poly bag, maximum collar diameter was with S+B+FYM mixture (0.91cm) followed by R+B+FYM mixture (0.86cm), R+FYM mixture (0.79) while minimum collar diameter was recorded with B+FYM mixture (0.75cm). Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed in polythene bag and nursery bed with different soil mixtures.

At the termination of study *i.e.* after four months (120 days) of seed sowing, maximum collar diameter of the seedling was registered in polythene bag (1.31cm) in comparison to nursery bed (1.21cm) in different soil mixtures. In polythene bag, maximum collar diameter was with S+B+FYM mixture (1.40cm) followed by R+B+FYM mixture (1.35cm), R+FYM mixture (1.25cm) while minimum collar diameter was recorded with B+FYM mixture (1.23cm). Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed in polythene bag and nursery bed with different soil mixtures.

When we see the effect of different soil mixtures in nursery bed and polythene bag, collar diameter at S+B+FYM soil mixture was found to be best. Even in both the years, similar trend was also found in different days of seed sowing.

4.7.2.3: Total dry weight (g):

A perusal of data indicated (Table 4.21) that initially, at the 60 days of seed sowing; maximum total dry weight of the seedling was registered in poly bag (2.23g) in comparison to nursery bed (1.82g) in different soil mixtures. In polythene bag, maximum total dry weight was with S+B+FYM soil mixture (2.89g) followed by R+B+FYM mixture (2.54g), R+FYM mixture (1.87g) while minimum total dry weight was recorded with B+FYM mixture (1.60g). Same trend was observed in

nursery bed condition. Even in both the years, similar trend was observed in polythene bag and nursery bed with different soil mixtures.

At the final observations *i.e.* after four months (120 days) of seed sowing, maximum total dry weight of the seedling was registered in polythene bag (11.31g) in comparison to nursery bed (9.30g) in different soil mixtures. In polythene bag, maximum total dry weight was with S+B+FYM mixture (14.52g) followed by R+B+FYM mixture (12.29g), R+FYM mixture (10.49g) while minimum total dry weight with B+FYM mixture (7.95g) which was significantly lower than S+B+FYM and R+B+FYM soil mixtures. Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed in polythene bag and nursery bed with different soil mixtures.

When we see the effect of different soil mixtures in nursery bed and polythene bag, total dry weight at S+B+FYM soil mixture was found to be best. Even in both the years, similar trend was also found in different days of seed sowing.

4.7.3: Growth analysis parameters:

Relative Growth Rate, Net Assimilation Rate, Specific Leaf weight has marked influence on the final out come. Hence, in the present study these three parameters were studied and the results have been presented Table 4.21.

4.7.3.1: Relative Growth Rate [RGR] ($\text{g g}^{-1} \text{d}^{-1}$):

Relative Growth Rate of *Jatropha curcas* seedlings under the influence of different soil mixtures in nursery bed and polythene bag on seedling growth was worked out at 30 days interval. The data has been presented in Table 4.21. At the termination of study, 90-120days of interval, the results indicated that RGR values were maximum (0.030) in polythene bag, in comparison to nursery bed (0.26) in different soil mixtures. In polythene bag, maximum RGR was with S+B+FYM soil mixture (0.036) followed by R+B+FYM mixture (0.030), R+FYM mixture (0.027) while minimum RGR was recorded with B+FYM soil mixture (0.025).

Table 4.21: Effect of different soil mixtures on different growth parameters in *Jatropha curcas*

DAS	Soil mixtures	2005		2006		Mean	
		Nursery bed	Polythene bag	Nursery bed	Polythene bag	Nursery bed	Polythene bag
Plant height (cm)							
30	B+FYM	18.23	19.74	10.61	12.35	14.42	16.05
	R+FYM	19.35	21.89	12.53	13.26	15.94	17.58
	R+B+FYM	20.72	22.34	14.29	15.01	17.51	18.68
	S+B+FYM	21.37	22.37	15.86	18.05	18.62	20.21
	Mean	19.92	21.59	13.32	14.67	16.62	18.13
	LSD(0.05)	0.17	NS	NS	3.80	2.89	3.55
60	B+FYM	28.72	31.64	17.59	19.31	23.16	25.48
	R+FYM	31.71	37.67	18.69	22.40	25.20	30.04
	R+B+FYM	33.45	38.78	22.81	23.87	28.13	31.33
	S+B+FYM	33.46	45.14	23.82	26.48	28.64	35.81
	Mean	31.84	38.31	20.73	23.02	26.28	30.67
	LSD(0.05)	NS	NS	2.48	4.48	5.39	7.09
90	B+FYM	33.72	39.64	27.30	30.06	30.51	34.85
	R+FYM	37.54	45.24	29.11	30.17	33.33	37.71
	R+B+FYM	39.33	49.45	30.79	32.78	35.06	41.12
	S+B+FYM	39.52	53.97	32.83	32.85	36.18	43.41
	Mean	37.53	47.08	30.01	31.47	33.77	39.27
	LSD(0.05)	NS	7.06	NS	NS	NS	5.78
120	B+FYM	43.20	49.89	34.40	35.51	38.80	42.70
	R+FYM	46.67	50.80	35.44	35.97	41.06	43.39
	R+B+FYM	47.89	56.38	36.14	38.78	42.02	47.58
	S+B+FYM	48.92	62.75	36.24	38.98	42.58	50.87
	Mean	46.67	54.96	35.56	37.31	41.12	46.14
	LSD(0.05)	NS	12.73	NS	NS	NS	6.40
Collar diameter (cm)							
30	B+FYM	0.57	0.58	0.53	0.57	0.55	0.58
	R+FYM	0.58	0.62	0.58	0.59	0.58	0.61
	R+B+FYM	0.61	0.63	0.61	0.64	0.61	0.64
	S+B+FYM	0.64	0.69	0.62	0.65	0.63	0.67
	Mean	0.60	0.63	0.59	0.61	0.59	0.63
	LSD(0.05)	NS	NS	NS	NS	NS	0.08
60	B+FYM	0.76	0.77	0.67	0.73	0.72	0.75
	R+FYM	0.82	0.83	0.72	0.75	0.77	0.79
	R+B+FYM	0.83	0.88	0.78	0.84	0.81	0.86
	S+B+FYM	0.85	0.96	0.79	0.86	0.82	0.91
	Mean	0.82	0.86	0.74	0.80	0.78	0.83
	LSD(0.05)	NS	NS	0.09	NS	0.06	NS
90	B+FYM	0.96	1.03	0.96	1.05	0.96	1.04
	R+FYM	0.99	1.08	0.97	1.06	0.98	1.07
	R+B+FYM	1.05	1.15	1.05	1.11	1.05	1.13
	S+B+FYM	1.08	1.27	1.07	1.12	1.08	1.19
	Mean	1.02	1.13	1.01	1.09	1.02	1.11
	LSD(0.05)	NS	0.13	NS	NS	NS	NS
120	B+FYM	1.21	1.27	1.14	1.18	1.18	1.23
	R+FYM	1.23	1.30	1.15	1.20	1.19	1.25
	R+B+FYM	1.24	1.40	1.18	1.40	1.21	1.35
	S+B+FYM	1.32	1.45	1.19	1.25	1.26	1.40
	Mean	1.25	1.36	1.17	1.26	1.21	1.31
	LSD(0.05)	NS	NS	NS	NS	NS	NS

Total dry weight (g)							
30	B+FYM	0.58	0.77	0.53	0.90	0.56	0.84
	R+FYM	1.07	1.39	0.63	0.94	0.85	1.17
	R+B+FYM	1.21	1.63	0.67	1.19	0.94	1.41
	S+B+FYM	1.25	1.95	0.78	1.56	1.02	1.76
	Mean	1.03	1.44	0.65	1.15	0.84	1.30
	LSD(0.05)	0.49	NS	NS	NS	0.68	NS
60	B+FYM	1.49	1.86	1.28	1.33	1.38	1.60
	R+FYM	2.01	2.09	1.53	1.64	1.77	1.87
	R+B+FYM	2.18	2.88	1.67	2.20	1.93	2.54
	S+B+FYM	2.45	3.53	1.97	2.26	2.21	2.89
	Mean	2.03	2.59	1.61	1.86	1.82	2.23
	LSD(0.05)	NS	NS	NS	NS	NS	NS
90	B+FYM	3.43	4.08	1.87	2.56	2.65	3.32
	R+FYM	4.16	5.25	3.29	4.08	3.73	4.67
	R+B+FYM	4.62	6.78	3.69	5.21	4.16	5.99
	S+B+FYM	5.54	8.02	5.16	6.86	5.35	7.44
	Mean	4.44	6.03	3.50	4.68	3.97	5.36
	LSD(0.05)	2.85	NS	2.04	NS	1.69	NS
120	B+FYM	6.65	7.39	6.14	8.50	6.40	7.95
	R+FYM	6.95	10.44	8.41	10.53	7.68	10.49
	R+B+FYM	11.45	13.15	10.62	11.44	11.04	12.29
	S+B+FYM	11.59	13.79	12.53	15.24	12.06	14.52
	Mean	9.16	11.19	9.43	11.43	9.30	11.31
	LSD(0.05)	NS	NS	NS	NS	NS	4.09
Relative Growth Rate ($\text{g g}^{-1} \text{d}^{-1}$)							
30-60	B+FYM	0.011	0.019	0.013	0.03	0.012	0.025
	R+FYM	0.015	0.022	0.014	0.03	0.015	0.026
	R+B+FYM	0.019	0.022	0.018	0.034	0.019	0.028
	S+B+FYM	0.025	0.032	0.025	0.034	0.025	0.033
	Mean	0.018	0.024	0.018	0.032	0.018	0.028
60-90	B+FYM	0.019	0.026	0.021	0.022	0.016	0.024
	R+FYM	0.023	0.029	0.025	0.029	0.024	0.029
	R+B+FYM	0.027	0.033	0.028	0.031	0.028	0.032
	S+B+FYM	0.029	0.033	0.031	0.037	0.03	0.035
	Mean	0.025	0.030	0.026	0.030	0.025	0.030
90-120	B+FYM	0.018	0.022	0.023	0.031	0.022	0.025
	R+FYM	0.022	0.024	0.024	0.031	0.024	0.027
	R+B+FYM	0.026	0.026	0.032	0.034	0.027	0.03
	S+B+FYM	0.03	0.032	0.039	0.039	0.031	0.036
	Mean	0.024	0.026	0.030	0.034	0.026	0.030
Net Assimilatory Rate ($\text{mg cm}^{-2} \text{d}^{-1}$)							
30-60	B+FYM	0.15	0.07	0.18	0.08	0.17	0.07
	R+FYM	0.17	0.13	0.21	0.13	0.19	0.13
	R+B+FYM	0.17	0.14	0.20	0.23	0.19	0.19
	S+B+FYM	0.23	0.27	0.32	0.09	0.28	0.18
	Mean	0.18	0.15	0.23	0.13	0.21	0.14
60-90	B+FYM	0.12	0.18	0.09	0.13	0.10	0.16
	R+FYM	0.13	0.18	0.12	0.15	0.13	0.17
	R+B+FYM	0.17	0.20	0.16	0.18	0.17	0.19
	S+B+FYM	0.21	0.18	0.21	0.26	0.21	0.22
	Mean	0.16	0.19	0.15	0.18	0.15	0.19
90-120	B+FYM	0.15	0.17	0.22	0.20	0.19	0.19
	R+FYM	0.16	0.19	0.27	0.20	0.22	0.20
	R+B+FYM	0.24	0.20	0.29	0.23	0.27	0.22
	S+B+FYM	0.25	0.17	0.31	0.28	0.28	0.23
	Mean	0.20	0.18	0.27	0.23	0.21	0.24
Specific Leaf weight (mg cm^{-2})							
30	B+FYM	4.40	4.30	3.60	4.40	4.00	4.40

	R+FYM	4.50	4.40	4.30	4.90	4.40	4.70
	R+B+FYM	5.30	4.70	6.50	7.30	5.90	6.00
	S+B+FYM	5.50	4.80	7.10	110	6.30	7.90
	Mean	4.93	4.55	5.38	31.65	5.15	5.75
	B+FYM	3.00	3.00	2.20	2.20	2.60	2.60
60	R+FYM	3.20	3.00	2.80	2.80	2.90	3.00
	R+B+FYM	3.40	3.70	3.20	3.40	3.30	3.60
	S+B+FYM	4.60	4.00	3.30	6.40	3.95	5.20
	Mean	3.55	3.43	2.88	3.70	3.19	3.60
	B+FYM	3.10	2.50	3.20	2.10	2.30	3.20
90	R+FYM	3.10	2.80	3.50	2.40	2.60	3.30
	R+B+FYM	2.60	3.10	5.00	2.40	2.80	3.80
	S+B+FYM	3.50	3.40	5.70	3.30	4.60	3.40
	Mean	3.08	2.95	4.35	2.55	3.08	3.43
	B+FYM	2.70	3.60	2.30	3.00	2.50	3.30
120	R+FYM	2.90	3.60	2.90	3.80	2.90	3.70
	R+B+FYM	3.00	4.10	3.80	3.80	3.40	4.00
	S+B+FYM	5.80	4.20	4.30	4.20	4.20	5.05
	Mean	3.60	3.88	3.33	3.70	3.25	4.01
Root: Shoot ratio							
30	B+FYM	0.20	0.21	0.29	0.43	0.25	0.32
	R+FYM	0.26	0.26	0.30	0.45	0.28	0.36
	R+B+FYM	0.36	0.44	0.38	0.48	0.37	0.46
	S+B+FYM	0.43	0.46	0.44	0.50	0.44	0.48
	Mean	0.31	0.34	0.35	0.47	0.34	0.41
60	LSD(0.05)	NS	NS	NS	NS	NS	NS
	B+FYM	0.19	0.24	0.24	0.28	0.22	0.26
	R+FYM	0.21	0.25	0.26	0.32	0.24	0.29
	R+B+FYM	0.28	0.40	0.29	0.32	0.29	0.36
	S+B+FYM	0.30	0.41	0.30	0.35	0.30	0.38
90	Mean	0.25	0.33	0.27	0.32	0.26	0.32
	LSD(0.05)	NS	NS	NS	NS	NS	NS
	B+FYM	0.17	0.15	0.25	0.28	0.21	0.22
	R+FYM	0.20	0.16	0.27	0.31	0.24	0.24
	R+B+FYM	0.22	0.16	0.30	0.30	0.26	0.23
120	S+B+FYM	0.20	0.17	0.31	0.32	0.26	0.25
	Mean	0.20	0.16	0.28	0.30	0.24	0.24
	LSD(0.05)	NS	NS	NS	NS	NS	NS
	B+FYM	0.17	0.17	0.22	0.31	0.20	0.24
	R+FYM	0.17	0.17	0.23	0.33	0.20	0.25
	R+B+FYM	0.18	0.16	0.25	0.33	0.22	0.25
	S+B+FYM	0.19	0.17	0.34	0.36	0.27	0.27
	Mean	0.18	0.17	0.26	0.33	0.22	0.25
	LSD(0.05)	NS	NS	NS	NS	NS	0.03
Height: Stem dry weight (cm g ⁻¹)							
30	B+FYM	37.54	49.45	33.22	48.59	35.38	49.02
	R+FYM	41.3	49.84	51.83	54.99	48.15	50.84
	R+B+FYM	45.1	56.8	56.09	63.58	50.6	60.19
	S+B+FYM	80.66	82.69	61.69	66.78	71.18	74.74
	Mean	51.15	59.70	50.71	58.49	51.33	58.70
60	LSD(0.05)	20.45	NS	NS	NS	NS	NS
	B+FYM	38.77	44.35	31.72	32.16	38.26	35.25
	R+FYM	49.31	54.05	35.45	37.99	42.38	46.02
	R+B+FYM	50.43	64.65	39.02	45.43	44.73	55.04
	S+B+FYM	55.49	73.27	38.12	60.76	46.81	67.02
90	Mean	48.5	59.08	36.08	44.09	43.05	50.83
	LSD(0.05)	NS	NS	NS	NS	NS	NS
	B+FYM	14.03	17.75	11.5	18.28	12.77	18.02
	R+FYM	16.35	21.25	15.4	22.77	15.88	22.01

R+B+FYM	19.16	23.04	21.54	23.25	20.35	23.15
S+B+FYM	27.34	28.05	29.57	42.27	28.81	34.81
Mean	19.22	22.52	19.50	26.64	19.45	24.50
LSD(0.05)	NS	NS	10.43	NS	10.04	NS
B+FYM	7.74	8.66	7.01	7.11	7.38	7.89
R+FYM	9.15	15.57	8.5	10.6	8.83	13.09
R+B+FYM	9.44	10.32	7.35	8.47	8.4	9.39
S+B+FYM	15.43	18.17	10.51	17.58	12.97	17.88
Mean	10.44	13.18	8.34	10.94	9.40	12.06
LSD(0.05)	3.18	NS	4.21	NS	4.37	NS

DAS: Days after sowing, B+FYM: Black soil + Farm Yard Manure, R+FYM: Red soil + Farm yard manure, R+B+FYM: Red soil+ Black soil + Farm Yard Manure, S+B+FYM: Sand + Black soil Farm Yard Manure

Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed in polythene bag and nursery bed with different soil mixtures.

RGR expresses the dry weight increase in a time interval in relation to the initial weight. Gardner *et al.* (1985) reported that RGR of crop plants generally begins slowly, peaks rapidly soon afterward and then falls off. Species vary in RGR.

4.7.3.2: Net Assimilatory Rate [NAR] ($\text{mg cm}^{-2} \text{d}^{-1}$):

Net Assimilatory Rate of *Jatropha curcas* seedlings under the influence of different soil mixtures in nursery bed and polythene bag on seedling growth was worked out at 30 days interval. The data has been presented in Table 4.21. At the time of final observation, 90-120days of interval, data shows that maximum NAR (0.24) was recorded in polythene bag in comparison to nursery bed (0.21) in different soil mixtures.

In polythene bag, maximum NAR was with S+B+FYM mixture (0.23) followed by R+B+FYM mixture (0.22), R+FYM mixture (0.20) while minimum NAR was recorded with B+FYM mixture (0.19). Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed in polythene bag and nursery bed with different soil mixtures. NAR depicts net gain of assimilates per unit of leaf area and time. In present investigation, NAR values increased during 90-

120 days. Hunt (1978) reported that NAR is not constant with time but shows an ontogenetic downward drift with plant age.

4.7.3.3: Specific leaf weight [SLW] (mg cm^{-2}):

Specific leaf weight of *Jatropha curcas* seedlings at monthly interval up to four month of age for seeds sown in different shade levels was recorded and presented in Table 4.21. Data reveals that, at 60 days of seed sowing, maximum SLW of the seedling registered in polythene bag (3.6) in comparison to nursery bed (3.19) in different soil mixtures. In polythene bag, maximum SLW was with S+B+FYM mixture (5.20) followed by R+B+FYM mixture (3.60), R+FYM mixture (3.00) SLW while minimum was recorded with B+FYM mixture (2.60).

Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed in polythene bag and nursery bed with different soil mixtures. With further increase in age, SLW per plant showed marginal change.

At the time of final observation (after 120 days of seed sowing), maximum SLW of the seedling was in polythene bag (4.01) in comparison to nursery bed (3.25) in different soil mixtures. In polythene bag, maximum SLW was with S+B+FYM mixture (5.05) which was higher than different soil mixtures followed by R+B+FYM mixture (4.00), R+FYM mixture (3.70) SLW while minimum was recorded with B+FYM mixture (3.30). Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed in polythene bag and nursery bed with different soil mixtures.

4.7.3.4: Root: Shoot ratio:

Data pertaining to Root: shoot ratio has been presented in Table (4.21). At the 60 days of seed sowing, maximum root shoot ratio of the seedling was in polythene bag (0.32) in comparison to nursery bed (0.26) root shoot ratio in different soil mixtures. In polythene bag, maximum root shoot ratio was with S+B+FYM mixture (0.38) which was higher than different soil mixtures followed by R+B+FYM mixture

(0.36), R+FYM mixture (0.29) while minimum root shoot ratio was recorded with B+FYM mixture (0.26). Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed in polythene bag and nursery bed with different soil mixtures.

It is apparent from the data that an appreciable hike in root: shoot ratio has been observed. With the increase in age of seedling at four months age, at termination of study, the data indicated that maximum root: shoot ratio of the seedling was in polythene bag (0.25) in comparison to nursery bed (0.22) in different soil mixtures. In polythene bag, maximum root shoot ratio was with S+B+FYM mixture (0.27) followed by R+B+FYM mixture (0.25), R+FYM mixture (0.25) while minimum root shoot ratio was recorded with B+FYM mixture (0.24). Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed in polythene bag and nursery bed with different soil mixtures.

4.7.3.5: Height: Stem dry weight (cm g⁻¹):

Data on Height: Stem dry weight of *Jatropha curcas* seedlings at monthly interval as influenced by different soil mixtures in nursery bed and polythene bag have been presented in Table 4.21. At 60 days of seed sowing, maximum Height: Stem dry weight was recorded in polythene bag (50.83) in comparison to nursery bed (43.05) in different soil mixtures. In polythene bag, maximum Height: Stem dry weight was with S+B+FYM mixture (67.02) followed by R+B+FYM mixture (55.04), R+FYM mixture (46.02) while minimum Height: Stem dry weight was recorded with B+FYM mixture (35.25). Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed in polythene bag and nursery bed with different soil mixtures.

With the increase in age of seedling, at four months of age, the data indicated that maximum Height: Stem dry weight was recorded in in polythene bag (12.06) in comparison to nursery bed (9.40) in different soil mixtures. In poly thene bag, maximum Height: Stem dry weight was with S+B+FYM mixture (17.88) followed

by R+B+FYM mixture (13.09), R+FYM mixture (9.39) while minimum Height: Stem dry weight was recorded with B+FYM mixture (7.89). Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed in polythene bag and nursery bed with different soil mixtures.

Mughal (1996) studied that the *C.torulosa* and *C. deodara* attain optimum shoot root development when grown in open nursery in beds while as seedling grown in poly bag do not exhibit better growth in terms of height and root development. Roots of poly bags seedlings showed even deformities and confinement in immediately vicinity.

The comparison of the seedlings of various treatments is more authentic on the basis of quality parameters rather than on actual values of height or collar diameter. Seedling quality specifications have traditionally been based on certain morphological characteristics such as sturdiness (height/diameter ratio), root/shoot ratio and some other features (Aldhous, 1976, Cleary *et al.*, 1978). Seedling raised in polythene bag kept on nursery bed was observed to be sturdier than root trainer raised seedlings. The higher root shoot ratio and the ratio of fibrous/total root biomass help the plant in good survival and growth after planting (Chauhan and Sharma, 1997).

Improvement in polythene bag seedling production system has also been suggested by a number of researchers. Gera and Sharma (1995), Gera *et al.* (1996 a, 1998 b and 2000), have reported the use of polythene bags perforated at bottom and kept on Mounted Angle Iron (MAI) beds gave studier seedlings with significantly enhanced seedling quality parameters. Findings of present study were in conformity with above studies.

From the above results it is amply clear that polythene bags raised seedlings were better as they registered maximum root shoot ratio which are very important for better establishment and survival and growth of seedlings when transferred to field.

4.8: Effect of water stress on seedling growth of *Jatropha curcas*:

The experiment was conducted to study the effect of different shade levels *i.e.* alternate day, two days and three days along with control (daily) on seed germination behaviour, seedling growth, growth rate and biomass yield. The experiment was conducted under field conditions. The results have been presented below.

4.8.1: Germination Response:

4.8.1.1: Days taken to initiate and complete germination and germination percent:

Observations on germination per cent, initiation and completion of germination were recorded and presented in Table 4.22. It is apparent from the data that the germination percent was highest (88.33%) at control and it was followed alternate day watering (73.34%), after two days watering (70%) and minimum was recorded after three days watering (63.34%). Here we see that heavy water stress reduced the germination percent drastically. Even in both the years daily watering (control) was found to be best in comparison to alternate day, two days and three days of watering.

Germination percent was non-significant in various types of water stress levels. The table clearly indicates that with the increase in water stress level, initiation of germination was delayed. However, various water stress levels did not significantly influence days taken to initiate germination. Heavy water stress (3day gap) registered maximum days (9.00) to initiate germination, while minimum days taken to initiate germination were recorded under control (6.00 days). Even in both the years, minimum days taken to initiate germination were under control (daily watering) which was significantly lower than various water stress levels. Days taken to initiate and complete germination increased with increasing water stress level. Control was good for seed germination and seedling growth in *Jatropha curcas*. It may be attributed that seed required water to regulate the process of seed germination and seedling growth.

Table 4.22: Effect of different levels of water stress on initiation and completion of germination and germination percentage in *Jatropha curcas*

Water stress levels	Parameters								
	Initiation of germination (days)			Completion of germination (days)			Germination (%)		
	2005	2006	Pooled mean	2005	2006	Pooled mean	2005	2006	Pooled mean
1 day gap	5.67	8.00	6.84	10.67	13.33	12.00	90.00	56.67	73.34
2 day gap	6.00	8.33	7.17	11.33	14.67	13.00	86.67	53.33	70.00
3 day gap	6.67	11.33	9.00	12.67	16.00	14.34	76.67	50.00	63.34
Daily(Control)	5.33	6.67	6.00	10.33	13.00	11.67	93.33	83.33	88.33
LSD(0.05)	NS	0.73	1.08	NS	NS	NS	NS	NS	NS

Minimum days taken to complete germination were under control (11.67) followed by one day gap (12days), two day gap (13.00 days) while maximum days (14.34) to complete germination were recorded under three day gap. In completion of germination, there was no significant difference between different treatments. Even in both the years, minimum days taken to complete germination were under control and heavy water stress (3days gap) registered maximum days to complete germination. From present study, it is obvious that *Jatropha* seeds take 6.00 to 9.00 days to initiate and 11.67-14.34 days to complete germination.

Longer period to initiate germination is obviously due to scarcity of water. It is stony endocarp, which determines days taken to initiate and complete germination on account of imbibitions of water. Water stress conditions significantly affect the germination parameter in *Jatropha curcas*. Present data revealed that among all the four treatments (alternate day watering, two days watering, three days watering and the control *i.e.* daily watering), control was found to be excellent for all the germination related parameters and recorded maximum values for germination parameters. Even after three day gap, 63.34 per cent germination was recorded, thus it can be concluded from this experiment that *Jatropha curcas* can tolerate water stress to a large extent and germination values even at osmotic pressure were

comparatively good which may be the reason that this species is growing naturally in a wide climatic condition and well adopted to those conditions.

Reduction in seed germination at higher levels of water stress may possible be attributed to the moisture deficit in the seeds below the threshold which may lead to degradation and inactivation of essential hydrolytical and other groups of enzymes as suggested by Wilson, (1971). Present study concluded that *Jatropha curcas* can grow successfully at different water stress condition. This ability of species should give an advantage particularly where water stress level is end. The influence of water stress has a great significance on the seed germination and growth of seedlings.

Water is one of the most important inputs essential for the seed germination. Water stress condition affects the seed germination. The days taken to initiate and complete germination, delayed by increasing water stress condition in the species.

Humara *et al.* (2002) reported that excess deficit of water delayed the germination response in *Eucalyptus globules*. Increasing water stress significantly affect the days taken to initiate and complete germination. Mc Donough (1979) studied that the initiation of germination was delayed by increasing water stress condition in *Populus tremuloides*. Wilson (1971), Mc Donough (1979) and Sah *et al.* (1989) reported that increase in stress may reduce the water uptake, there by retarding the initiation of various metabolic processes due to degradation of essential hydrolytical and other group of enzymes involved in seed germination. Findings of the present study were in conformity with above study. Kramer and Kozlowski (1979) reported that water must be imbibed by the seed to increase protoplasmic hydration and setin motion the chain of metabolic events associated with germination.

4.8.2: Growth performance:

Growth observations at various water stress levels (alternate day watering, two days watering, three days watering and the control *i.e.* daily watering) were recorded at monthly interval up to four months in terms of plant height, collar diameter, Total dry weight, Root: Shoot ratio, Net Assimilatory rate, Relative Growth Rate, Specific

Leaf weight and Height: Stem dry weight. All the data have been presented in Table 4.23 at different days of observations.

4.8.2.1: Plant Height (cm):

The data presented in Table 4.23 reveals that after 60 days of sowing, maximum plant height of the seedling was registered under control *i.e.* daily watering (29.60cm), followed by alternate day watering (27.74cm) and minimum was recorded at three days interval (19.07cm). Seedling height was influenced by water stress levels through out the period of study. However, plant height at three days water stress level was significantly lower than alternate day gap, two days gap and control. When we see the effect of water stress levels, plant height under control was found to be best. Similar trend was also found in different days of seed sowing.

At the termination of study *i.e.* after four months (120 days) of seed sowing, maximum plant height of the seedling was registered under control (47.20cm), followed by alternate day gap (46.17cm) and minimum (35.14cm) was recorded at three days watering. Seedling height was influenced by water stress levels through out the period of study. However, plant height at three days gap water stress level was significantly lower than various types of water stress levels. When we see the effect of water stress levels, plant height at control was found to be best in different water stress levels. However, water continued to play major role in governing plant height. Even in both the years, similar trend was also recorded at various water stress levels.

4.8.2.2: Collar diameter (cm):

Collar diameter of *Jatropha curcas* seedlings at monthly interval up to four month of age was recorded and presented in Table 4.23. Data reveals that, at 60 days of seed sowing, maximum collar diameter (0.88cm) of the seedling was registered under control, followed by at one day gap (0.78cm) and minimum was recorded at three days gap of watering (0.66cm). At two days gap, height was recorded of 0.68cm. Seedling collar diameter was influenced by various water stress levels

through out the period of study. However, collar diameter at three days gap was significantly lower than one day and daily watering (Control). When we see the effect of water stress levels, collar diameter of the seedling at control was found to be best in different watering. Similar trend was also found in different days of seed sowing.

At the time of final observations *i.e.* after four months (120 days) of seed sowing, maximum collar diameter (1.44cm) of the seedling was registered under control, followed by at alternate day watering (1.37cm) and minimum (1.19cm) was recorded at three days gap of watering. At two days gap, collar diameter was recorded 1.29cm. Seedling collar diameter was influenced by various water stress levels through out the period of study. However, collar diameter at three days gap was significantly lower than alternate day and daily watering. When we see the effect of water stress levels, collar diameter of the seedling at control was found to be best in different watering. Even in both the years, similar trend was also recorded at various water stress levels.

4.8.2.3: Total dry weight (g):

A perusal of data indicated that initially, at the 60 days of seed sowing, maximum (2.36g) total dry weight of the seedling was registered under control, followed by at alternate day gap (1.70g) and minimum was recorded at three days gap (0.88g). At two days gap of watering, total dry weight was recorded 1.46g. Total dry weight of the seedling was influenced by water stress levels through out the period of study. However, total dry weight at three days gap level was significantly lower than alternate day gap and daily watering (control). When we see the effect of water stress levels, total dry weight at control was found to be best in different water stress levels. Similar trend was also found in different days of seed sowing.

At the time of final observations *i.e.* after four months (120 days) of seed sowing, maximum total dry weight of the seedling was registered under control (14.39g), followed by at alternate day gap (11.58g) and minimum was recorded at three days gap (4.58g). At two days gap, total dry weight was recorded 9.67g. Total

dry weight of seedling was influenced by water stress levels through out the period of study. However, total dry weight at three days gap of watering was significantly lower than alternate day gap, two days gap and control. Total dry weight at control was found to be best in different water stress levels. Even in both the years, similar trend was also recorded at various water stress levels.

4.8.3: Growth analysis parameters:

Relative Growth Rate, Net Assimilation Rate, Specific Leaf weight are very important parameters for understanding the growth behaviour of the plants. In the present study these three parameters were studied and the results have been presented Table 4.23.

4.8.3.1: Relative Growth Rate [RGR] ($\text{g g}^{-1} \text{d}^{-1}$):

Relative Growth Rate of *Jatropha curcas* seedlings under the influence of different types of water stress levels on seedling growth was worked out at 30 days interval. The data has been presented in Table 4.23. At the termination of study i.e. 90-120days of interval, the results indicated that RGR values were maximum registered under control (0.033) which was higher than different types of water stress levels, which was closely followed by alternate day gap (0.030). Minimum RGR was recorded at three days gap of watering (0.026). Even in both the years, similar trend was also recorded in different water stress levels.

RGR express the dry weight increase in a time interval in relation to the initial weight. Gardner *et al.* (1985) reported that RGR of crop plants generally begins slowly, peaks rapidly soon afterward and than falls off. Species vary in RGR. The effect of water stress on RGR did not show any definite trend during the course of investigation, however, mean values of RGR, showed reduction under heavy water stress (three days gap). Similar observations have been reported in *Quercus floribunda* and *Cupressus torulosa* by Rao (1988).

4.8.3.2: Net Assimilation Rate [NAR] ($\text{mg cm}^{-2} \text{ d}^{-1}$):

Net Assimilatory Rate of *Jatropha curcas* seedlings under the influence of different types of water stress on seedling growth was worked out at monthly interval. The data has been presented in Table 4.23. At the time of final observation *i.e.* 90-120 days of interval, it is apparent from the data that maximum NAR was registered under control (0.44) which was higher than other water stress levels, which was closely followed by alternate day gap (0.23), two days gap (0.20) while minimum was recorded at three days gap of watering (0.16). Even in both the years, similar trend was recorded at various water stress levels.

Table 4.23: Effect of different levels of water stress on various growth parameters in *Jatropha curcas* seeds

Water stress levels	DAS	2005						2006						Mean				
		2005						2006						Mean				
		1 day gap	2 day gap	3 day gap	Daily (Control)	LSD(0.05)		1 day gap	2 day gap	3 day gap	Daily (Control)	LSD(0.05)		1 day gap	2 day gap	3 day gap	Daily (Control)	LSD (0.05)
PH	30	21.57	18.60	15.38	22.32	2.39		15.37	13.60	12.89	15.92	1.52		18.47	16.10	14.14	19.12	1.77
	60	36.04	30.23	20.50	38.51	4.38		19.44	18.67	17.64	20.69	NS		27.74	24.45	19.07	29.60	3.77
	90	48.80	41.00	27.00	54.75	7.89		25.52	24.50	23.33	28.14	NS		37.16	32.75	25.17	41.45	5.40
	120	56.33	47.42	34.67	57.87	4.92		36.00	35.00	35.61	36.53	NS		46.17	41.21	35.14	47.20	3.38
CD	30	0.59	0.57	0.49	0.70	0.06		0.58	0.56	0.53	0.59	NS		0.59	0.57	0.51	0.65	0.06
	60	0.81	0.68	0.67	0.92	0.06		0.75	0.68	0.65	0.83	0.09		0.78	0.68	0.66	0.88	0.08
	90	1.18	1.16	1.02	1.24	NS		0.93	0.91	0.90	1.06	NS		1.06	1.04	0.96	1.15	0.08
	120	1.61	1.45	1.27	1.63	0.17		1.13	1.13	1.11	1.25	NS		1.37	1.29	1.19	1.44	0.16
TDW	30	0.89	0.72	0.43	0.99	NS		0.85	0.77	0.41	0.98	0.23		0.87	0.75	0.42	0.99	NS
	60	1.75	1.71	0.82	2.94	0.66		1.65	1.20	0.93	1.78	NS		1.70	1.46	0.88	2.36	0.73
	90	6.36	5.90	2.09	13.45	3.41		4.68	2.90	2.41	5.98	NS		5.52	4.40	2.25	9.72	2.10
	120	14.09	11.70	4.61	18.07	3.43		9.06	7.63	4.55	10.70	NS		11.58	9.67	4.58	14.39	3.55
RGR	30-60	0.028	0.027	0.023	0.050	-		0.022	0.021	0.020	0.026	-		0.025	0.024	0.022	0.038	-
	60-90	0.044	0.040	0.029	0.050	-		0.033	0.032	0.030	0.040	-		0.039	0.036	0.030	0.045	-
	90-	0.029	0.027	0.026	0.029	-		0.030	0.029	0.026	0.036	-		0.030	0.028	0.026	0.033	-
	120	0.23	0.20	0.22	0.42	-		0.24	0.12	0.19	0.25	-		0.24	0.16	0.21	0.34	-
NAR	30-60	0.27	0.23	0.19	0.55	-		0.24	0.23	0.15	0.33	-		0.26	0.23	0.17	0.44	-
	60-90	0.23	0.19	0.19	0.55	-		0.22	0.20	0.13	0.33	-		0.23	0.195	0.16	0.44	-
	90-	0.23	0.19	0.19	0.55	-		0.22	0.20	0.13	0.33	-		9.30	5.85	3.35	9.85	-
	120	5.60	5.50	4.70	5.70	-		13.00	6.20	2.00	14.00	-		3.95	3.25	3.10	4.35	-
SLW	30	3.50	3.40	3.30	4.10	-		4.400	3.10	2.90	4.60	-		3.50	2.80	2.55	4.80	-
	60	2.80	2.80	2.80	5.20	-		4.20	2.80	2.30	4.40	-		3.80	3.10	2.60	3.65	-
	90	3.80	3.80	2.90	3.30	-		3.80	2.40	2.30	4.00	-		3.80	3.10	2.60	3.65	-
	120	0.40	0.33	0.31	0.55	NS		0.40	0.32	0.31	0.60	NS		0.40	0.33	0.31	0.58	NS
R: S ratio	30	0.27	0.21	0.20	0.36	NS		0.33	0.26	0.23	0.41	NS		0.30	0.24	0.215	0.39	NS
	60	0.18	0.17	0.13	0.21	NS		0.22	0.20	0.19	0.29	NS		0.20	0.19	0.16	0.25	NS
	90	0.26	0.21	0.14	0.26	0.04		0.26	0.20	0.17	0.26	NS		0.26	0.21	0.155	0.26	NS
	120	102.77	67.94	64.19	127.58	NS		46.94	51.18	42.52	52.61	NS		74.86	59.56	53.36	90.10	NS
H: S dry wt.	30	52.42	44.54	28.60	67.20	NS		64.36	33.73	31.93	71.77	NS		58.39	39.14	30.27	69.49	NS
	60	16.07	15.21	6.60	35.86	NS		25.27	24.50	12.93	29.37	NS		20.67	19.86	9.77	32.62	NS
	90	8.15	8.02	7.11	14.59	NS		14.30	12.24	8.75	26.42	NS		11.23	10.13	7.93	20.51	8.09
	120																	

CD: Collar diameter (cm), TDW: Total dry weight (g), R: S ratio: Root: Shoot ratio, NAR: Net Assimilatory Rate (mg cm⁻² d⁻¹), RGR: Relative

DAS: Days after sowing, PH: Plant height (cm), CD: Collar diameter (cm), TDW: Total dry weight (g), R: S ratio: Root: Shoot ratio, NAR: Net Assimilatory Rate (mg cm⁻² d⁻¹), RGR: Relative Growth Rate (g g⁻¹ d⁻¹), SLW: Specific leaf weight (mg cm⁻²), H: S dry wt.: Height: Stem dry weight (cm g⁻¹)

Hunt (1978) reported that NAR is not constant with time but shows an ontogenetic downward drift with plant age. Increased competition for nutrient and other factors are also important as age and size increases.

4.8.3.3: Specific leaf weight SLW (mg cm^{-2}):

Specific leaf weight of *Jatropha curcas* seedlings at monthly interval up to four month of age were recorded and presented in Table 4.23. Data reveals that, at 60 days of seed sowing, maximum SLW of the seedling was under control (4.35) which was higher than various types of water stress levels, followed by alternate day gap (3.95) and minimum SLW was recorded at three days gap of watering (3.10). Even in both the years, similar trend was also recorded at various water stress levels.

At the time of final observation *i.e.* 120 days of seed sowing, maximum SLW of the seedling was under control (3.80) which was higher than various types of water stress levels, followed by alternate day gap (3.65) and minimum SLW was recorded at three days gap of watering (2.60). Even in both the years, similar trend was recorded at various water stress levels. SLW of seedling reduced with increase in sowing depth. The species shows seasonal growth behaviour and slow growth and therefore, duration of growing season plays vital role in the growth of SLW.

4.8.3.4: Root: Shoot ratio:

Data pertaining to Root: shoot ratio has been presented in Table (4.23). At the 60 days of seed sowing, the differences among various water stress levels were non significant. Maximum root shoot ratio of the seedling was under control (0.39) which was higher than various types of water stress levels, followed by alternate day gap (0.30) and minimum root shoot ratio was recorded at three days gap of watering (0.22). It is apparent from the data that root: shoot ratio decreased with the increase in age up to 3 month in all the treatments. An appreciable hike in root: shoot ratio has been observed at 4 months stage in all the water stress treatments, while control recorded high root: shoot ratio throughout the study period. Root shoot ratio was

influenced by various types of water stress levels through out the study period. Even in both the years, similar trend was also recorded at various water stress levels. Treatments show non-significant effects.

With the increase in age of seedling at four months (120 days) age, the data indicated that maximum root: shoot ratio of the seedling was under control (0.26) and same in alternate day gap which was higher than various types of water stress levels. Minimum root shoot ratio was recorded at three days gap of watering (0.16). Root shoot ratio was influenced by various types of water stress levels through out the study period. Even in both the years, control (daily watering) was found to be best in comparison to other water stress levels. Even in both the years, similar trend was also recorded at various water stress levels.

4.8.3.5: Height: Stem dry weight (cm g^{-1}):

Data on Height: Stem dry weight of *Jatropha curcas* seedlings at monthly interval have been presented in Table 4.23. At 60 days of seed sowing, the differences among various water stress levels were non significant. Maximum Height: Stem dry weight of the seedling was under control (64.49) which was higher than various types of water stress levels, followed by alternate day gap (58.39) and minimum Height: Stem dry weight was recorded at three days gap of watering (30.27). Even in both the years, similar trend was recorded at various water stress levels.

With the increase in age of seedling at four months (120 days) age, at termination of study, the data indicated that maximum Height: Stem dry weight of the seedling was under control (20.51) which was higher than various types of water stress levels, followed by alternate day gap (11.23) and minimum Height: Stem dry weight was recorded at three days gap of watering (7.93). At two days gap of watering, Height: Stem dry weight was 10.13. Height: Stem dry weight at three days gap of watering was significantly lower than control (daily watering). Height: Stem dry weight was influenced by various types of water stress levels through out the

study period. Even in both the years, control was found to be best in comparison to other water stress levels and similar trend was also recorded at various water stress levels. It is obvious from the data that Height: Stem dry weight decreased progressively with the advancement in age.

Water deficit also effect the growth and development of a plant directly and consequently its yield and quality. The growth of *Jatropha curcas* was also affected by water stress condition. Nautiyal *et al.* (1996) reported that heavy stress destroy both Chl. a and b resulting less photosynthesis and low growth (monthly watering interval). Pokhriyal *et al.* (1997) reported that seedling of *A. nilotica* shows markedly reductions in plant height, basal diameter, fresh and dry weight of leaf, stem, root as well as nitrogenous activity with the increase in moisture stress conditions or increase in the time interval between watering. Jha and Chaudhary (1998) studied the effect of different watering frequencies and reported that growth difference between watering frequencies were significant for *Albizia lebbek* (height and roots) and *C. equisetifolia* (height). Findings of present study were in conformity of above study and concluded that water stress condition significantly affects the growth behaviour of *Jatropha curcas*.

Summary and

Conclusion

SUMMARY AND CONCLUSION

The present investigation entitled "Study on seed germination, seedling growth and biomass production in *Jatropha curcas* L." was carried out at National Research Centre for Agroforestry, Jhansi during 2005-07.

Laboratory Experiment:

5.1: Effect of storage containers and duration of storage on seed germination:

Storage of seeds in different containers for varying time period significantly affects the germination and viability of seeds. Viability of seed, over the years was recorded maximum (82.55%) under air tight plastic jar container in different months followed by under plastic bag (77.42%) whereas it was minimum (65.75%) under earthen pot storage container.

The viability of seed was found maximum (54.7%) in air tight plastic container after 12 months of storage and it was followed by plastic bag (52%) and minimum (40.15%) was in earthen pot. Initiation and completion of seed germination over the years was recorded minimum (4.25 and 7.50 days) under air tight plastic jar container, followed by under plastic bag (4.75 and 8.63 days) whereas maximum days (7.0 and 10.38 days) were recorded under earthen pot storage container after 12 months of storage. Germination percent over the years was recorded maximum (72.20%) under air tight plastic jar container followed by 69.71 percent under plastic bag whereas minimum (50.90%) under earthen pot storage container.

Over the years, maximum MDG (12.49), GV (49.78) and VI (1514.48) were recorded under air tight plastic jar container followed by under plastic bag whereas minimum MDG (6.55), GV (12.31) and VI (850) were recorded under earthen pot.

5.2: Effect of pH and water stress on seed germination:

Effect of pH:

Days taken to initiate and complete the germination was minimum under the treatment pH 7 (1.14 and 5.57 days) and maximum under pH 9 (2.29 and 10.50 days), which was significantly higher than all the pH except for pH 6 (1.79 and 9.50 days). Germination percentage was recorded maximum (65.72) at pH 7 followed by pH 6 (41.43 %) and pH 5 (48.57 %) and minimum (34.29%) at pH 9. The control treatment *i.e.* pH 7 was excellent for all the germination related parameters. Similarly, maximum MDG (11.85), GV (23.88), VI (1282.10) and GSI (100.00) were recorded at pH 7 whereas minimum MDG (3.27), GV (3.54), VI (562.72) and GSI (39.55) were recorded under pH 9.

Effect of water stress:

Days taken to initiate and complete the germination were minimum under -5 bar water stress condition (2.0 and 7.50 days). There was no germination under -10 and -15 bar water stress condition. Similarly, maximum germination percentage (45 percent), GV (15.09), VI (587.50) and GSI (48.03) were recorded under -5 bar.

5.3: Effect of different light and temperature on seed germination:

Effect of light:

The seed germination percentage was maximum in control *i.e.* white light (61.22%), followed by red light (47.50%) and far red (42.15%) and was minimum under dark condition (27.14%). The germination was significantly higher in control and red light condition as compared to dark condition. Days taken to initiate and complete the germination were earliest in control *i.e.* white light (1.28 and 5.57 days) followed by red light (1.29 and 9.22 days), far red (1.86 and 11.50 days) and maximum in dark condition (3.08 and 12.29 days). In control *i.e.* MDG (11.02), GV (23.88) and VI (1282.10) was recorded maximum under white light followed by red,

MDG (5.26), GV (13.80) and VI (877.15) whereas, minimum was recorded under dark condition, MDG (2.21), GV (3.53) and VI (484.69).

Effect of temperature:

Days taken to initiate and complete the germination were minimum (1.43 and 7.79 days) at 30°C and maximum (2.36 and 11.79 days) at 25°C. Maximum germination percentage (67.86) was recorded at 30°C, followed by 35°C (37.86%) and minimum germination (30%) was recorded at 25°C. Similarly, maximum MDG (9.11), GV (39.21) and VI (1139.3) was recorded at 30°C temperature whereas, minimum under 25°C temperature i.e. MDG (2.56), GV (6.20), and VI (414.43). At all the treatments, treatment (30°C) excelled for all the germination related parameters.

Field Experiments

5.4: Effect of time and depth of sowing on germination and seedling growth:

Minimum number of days taken to initiate germination was registered at 2cm depth in different months of sowing, while those sown at 4cm depth took maximum days to initiate germination. Month of March was found to be the best in comparison of other months.

Days taken to initiate and complete the germination were minimum in the month of March (6.38 to 11.59 days) and maximum in the month of November (13.92 and 19.21 days) and days taken to initiate and complete germination was minimum days at 2cm depth (7.28 and 12.50 days), followed by 1cm depth (8.78 and 13.88 days) and maximum at the depth of 4cm (11.03 and 16.28 days). In general, time taken to initiate germination increased with increase in depth of sowing through out the period of study. When we see the effect of depth of sowing in different months, sowing at the depth of 2cm was found to be best in different months of sowing i.e. March (4.67 and 9.84 days) followed by July (5.17 and 10.34 days) and

initiation of germination was maximum in the month of November (12.0 and 17.43 days).

Maximum (72.51%) germination percentage was recorded during the month of March followed by July (61.51%) and minimum (50.17%) in the month of November. Similarly, germination percentage was maximum at 2cm depth (69.45%) followed by 1cm depth (63.12%) and minimum was at the depth of 4cm (54.44%). Germination percentage at 2cm depth was significantly higher than 3 and 4cm depth. When we see the effect of depth of sowing in different months, sowing at the depth of 2 cm was found to be best in different months of sowing *i.e.* March (83.34%) followed by July (70%) and November (55.00%).

At the termination of study *i.e.* after four months (120 days) of seed sowing, maximum plant growth was recorded in the month of March *i.e.* PH (48.11cm), CD (1.33cm), TDW (3.89g), RGR (0.023), NAR (0.15), SLW (3.88), root shoot ratio (0.25), above ground biomass (9.20g) and below ground biomass (1.26g) and minimum in the month of November *i.e.* PH (10.08cm), CD (0.87cm), TDW (2.66g), RGR (0.013), NAR (0.09), SLW (3.24), root shoot ratio (0.21), above ground biomass (1.50g) and below ground biomass (0.27g). Maximum growth *i.e.* PH (34.43cm), CD (1.24cm), TDW (3.45g), RGR (0.020), NAR (0.14), SLW (3.65), root shoot ratio (0.24), above ground biomass (6.96g) and below ground biomass (1.00g) was recorded under 2cm depth followed by 1cm depth and minimum at the depth of 4 cm *i.e.* PH (28.55cm), CD (1.02cm), TDW (2.93g), RGR (0.016), NAR (0.10), SLW (2.83), root shoot ratio (0.21), above ground biomass (3.74g) and below ground biomass (0.55g). When we see the effect of depth of sowing in different months, plant height at the depth of 2cm was found to be best in different months of sowing *i.e.* March with PH (52.13cm), CD (1.58cm), TDW (4.30g), RGR (0.025), NAR (0.16), SLW (4.30), root shoot ratio (0.27), above ground biomass (12.33g) and below ground biomass (1.70g) followed by July with PH (40.34cm), CD (1.21cm), TDW (3.25g), RGR (0.021), NAR (0.14), SLW (3.75), root shoot ratio (0.22), above ground biomass (6.56g) and below ground biomass (0.88g) and minimum in the

month of November with PH (10.82cm), CD (0.93cm) TDW (2.80g), RGR (0.15), NAR (0.09), SLW (2.90), root shoot ratio (0.22), above ground biomass (1.99g) and below ground biomass (0.42g).

5.5: Effect of shade on seed germination and seedling growth:

The germination percent was highest at 35% shade level (70%) followed by control (58.34%), 50% shade level (51.67%) and minimum (41.67%) at 75% shade level was recorded. Here we see that heavy shade reduced the germination percent drastically. Days taken to initiate and complete germination were minimum (6.17 and 10.50) under 35% shade followed by control (7.0 and 12.17 days) and maximum (8.0 and 15.17) under heavy shade (75%). Even in both the years 35% shade level was found to be best in comparison to control and shade level of 50% and 75%.

At the final observations of study *i.e.*, after 120 days, maximum growth *i.e.*, PH (44.56cm), CD (1.55cm), TDW (12.47g), RGR (0.033), NAR (0.29), SLW (3.94) root shoot ratio (0.26) and Height: Stem dry weight of the seedling (18.50) was registered at 50% shade level, followed by 35% shade level and minimum at 75% shade level *i.e.* PH (35.79cm), CD (1.19cm), TDW (5.81), RGR (0.016), NAR (0.13), SLW (2.81), root shoot ratio (0.17) and Height: Stem dry weight (7.87). Even in both the years, 50% shade level was found to be best in comparison to other shade levels.

5.6: Studies on comparison of growth performance of poly bag and seedbed grown seedlings:

Days taken to initiate and complete germination were recorded minimum in polythene bag (7.34 and 12.30 days) in comparison to nursery bed (7.63 and 13.71 days) in different soil mixtures. In polythene bag, days taken to initiate and complete germination were minimum (6.67 and 10.84 days) with S+B+FYM mixture followed by R+B+FYM mixture (7.17 and 11.67 days), while maximum days (8.0 and 13.50 days) were recorded with B+FYM mixture. Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed.

Germination percentage was recorded highest in polythene bag (79.59%) in comparison to nursery bed (70.42%) in different soil mixtures. In polythene bag, maximum germination percentage (88.34%) was recorded with S+B+FYM mixture followed by R+B+FYM mixture (83.33%), while minimum (73.33%) with B+FYM mixture. Germination percentage with S+ B+FYM mixture was significantly higher than B+FYM and R+FYM mixture. Same trend was observed in nursery bed condition. Even in both the years, similar trend was observed. Raising seedlings of tree species in nursery is a common phenomenon all over the world in present day plantation programme of agroforestry and forestry. The findings of present study showed that polythene bag is suitable for the fast germination of the seeds of *Jatropha curcas*.

At the time of final observation *i.e.* after 120days of seed sowing, in polythene bag maximum growth *i.e.* PH (46.14cm), CD (1.31cm), TDW (11.31g), RGR (0.030), NAR (0.24), SLW (4.01), root: shoot ratio (0.25) and Height: Stem dry weight (12.06) was recorded in comparison to nursery bed *i.e.* PH (41.12cm), CD (1.21cm), TDW (9.30g), RGR (0.26), NAR (0.21), SLW (3.25), root shoot ratio (0.22) and Height: Stem dry weight (9.40) in different soil mixtures. In polythene bag, maximum growth *i.e.* PH (50.87cm), CD (1.40cm), TDW (14.52g), RGR (0.036), NAR (0.23), SLW (5.05) root: shoot ratio(0.27) and Height: Stem dry weight (17.88) was recorded under S+B+FYM mixture followed by R+B+FYM mixture while minimum was recorded under B+FYM soil mixture *i.e.* PH (42.70cm), CD (1.23cm), TDW (7.95g) RGR (0.025), NAR (0.19), SLW (3.30), root shoot ratio (0.24) and Height: Stem dry weight (7.89). When we see the effect of different soil mixtures in nursery bed and polythene bag, S+B+FYM soil mixture was found to be best.

5.7: Effect of water stress in seedling growth:

The germination percent was highest (88.33%) in control, followed by alternate day watering (73.34%) and minimum after three days watering (63.34%). Here we see that heavy water stress reduced the germination percent drastically. With

the increase in water stress level, initiation of germination was delayed. From present study, it is obvious that *Jatropha* seeds take 6.00 days to initiate germination under control condition (daily watering) whereas it takes 9.00 days to initiate under heavy water stress (3 days gap). Similarly, in control condition 11.67 days were taken to complete the germination whereas 14.34 days were taken under heavy water stress condition (3 days gap).

At the time of final observation i.e. after 120 days of seed sowing, maximum plant growth i.e. PH (47.20 cm), CD (1.44 cm), TDW (14.39 g), RGR (0.033), NAR (0.44), SLW (3.80), root: shoot ratio (0.26) and Height: Stem dry weight of the seedling was recorded under control (20.51) and minimum at three days gap of watering i.e. PH (35.14 cm), CD (1.19 cm), TDW (4.58 g), RGR (0.026), NAR (0.16), SLW (7.93), root shoot ratio (0.16) and Height: Stem dry weight (2.60). Even in both the years, control (daily watering) was found to be best in comparison to other water stress levels.

Conclusion

1. Viability of seed in different months were recorded maximum under air tight plastic jar container followed by plastic bag whereas it was minimum under earthen pot storage container. Initiation and completion of seed germination was earliest under air tight plastic jar container, followed by under plastic bag whereas maximum days were recorded under earthen pot storage container after 12 months of storage. Germination percent was recorded maximum under air tight plastic jar container followed by plastic bag whereas minimum under earthen pot storage container. Maximum MDG, GV and VI were recorded under air tight plastic jar container whereas minimum under earthen pot.
2. Germination percentage was recorded maximum at pH 7 followed by at pH 6 and pH 5 (48.57 %) and minimum at pH 9. Maximum MDG, GV, VI and GSI were recorded at pH 7 whereas minimum at pH 9.

3. Days taken to initiate and complete the germination were minimum under -5 bar water stress condition. There was no germination under -10 and -15 bar water stress condition. Similarly, maximum germination percentage, GV, VI and GSI were recorded under -5 bar water stress condition.

4. Seed germination percentage was maximum in control *i.e.* white light, followed by red light and far red and was minimum under dark condition. Days taken to initiate and complete the germination were earliest in control *i.e.* white light followed by red light, far red and maximum in dark condition. MDG, GV and VI were recorded maximum under white light followed by red light whereas minimum was recorded under dark condition.

5. Maximum germination percentage was recorded at 30°C, followed by 35°C and minimum germination was recorded at 25°C. Similarly, maximum MDG, GV and VI were recorded at 30°C temperature whereas, minimum under 25°C temperature. At all the treatments, treatment (30°C) excelled for all the germination related parameters.

6. When we see the effect of depth of sowing in different months, sowing at the depth of 2cm was found to be best in different months of sowing. Irrespective of depth of sowing, month of March was found to be the best in comparison of other months. All the growth parameters were found to be best at 2cm depth in the month of March.

7. The germination percent was highest at 35% shade level followed by control (Open), 50% shade level and minimum at 75% shade level. Maximum growth *i.e.*, PH, CD, TDW, RGR, NAR, SLW, Root shoot ratio and height: stem dry weight of the seedling was registered at 50% shade level, followed by 35% shade level and minimum at 75% shade level.

8. Germination and growth related parameters were best under polythene raised seedlings in comparison to nursery bed grown seedlings. Among the soil mixtures, performance of S+ B+FYM mixture was significantly higher than R+B+FYM, R+FYM and B+FYM mixture.

9. The germination percent was highest in control (daily watering), followed by alternate day watering and minimum after three days watering. Here we see that heavy water stress reduced the germination percent drastically. With the increase in water stress level, initiation of germination was delayed. Maximum plant growth *i.e.* PH, CD, TDW, RGR, NAR, SLW, Root: shoot ratio and height: stem dry weight of the seedling was recorded under control and minimum at three days gap of watering.

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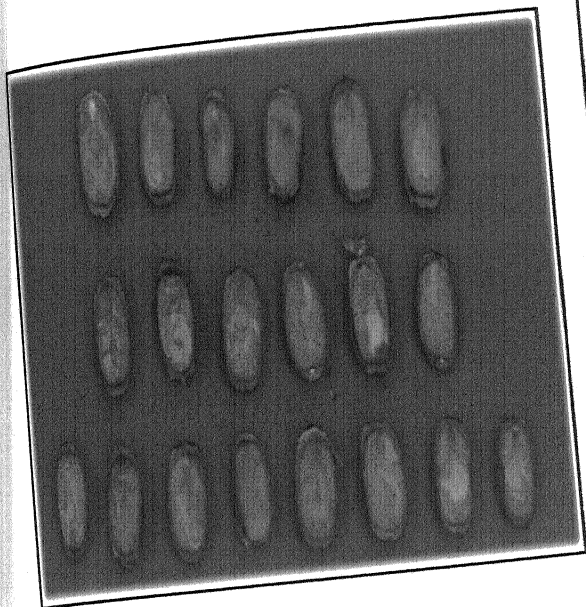
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Pictorial Section

Laboratory

Photo

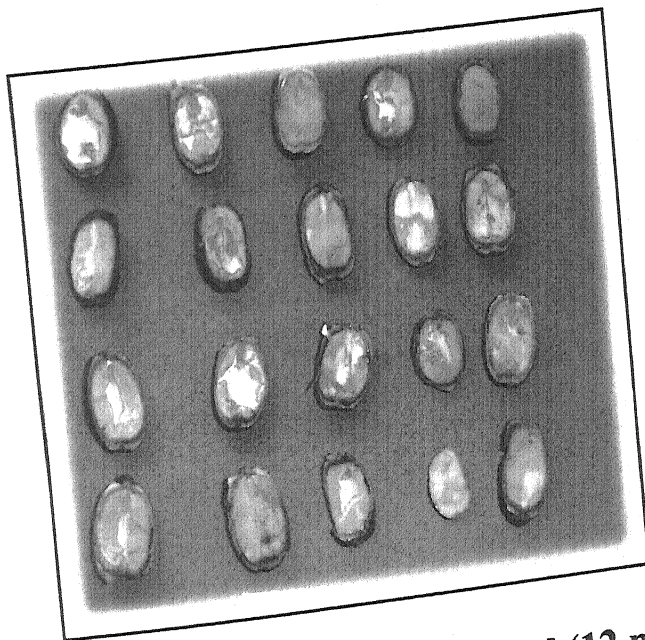
Effect of Storage containers and duration on seed viability



Viability in control

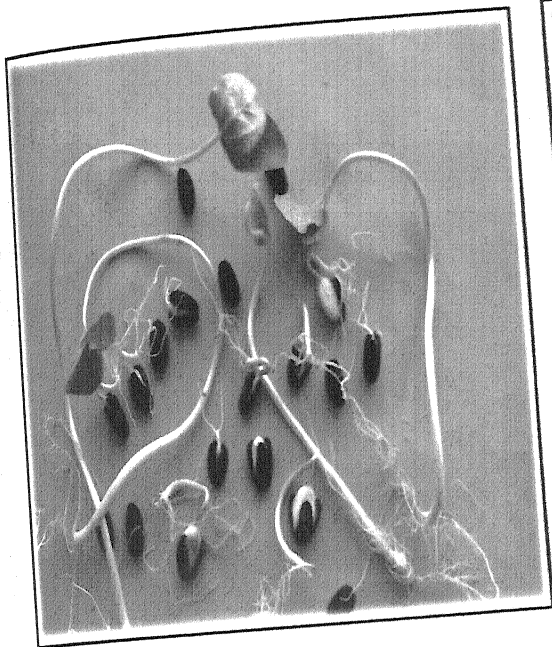


Viability in air tight plastic jar (12 months)

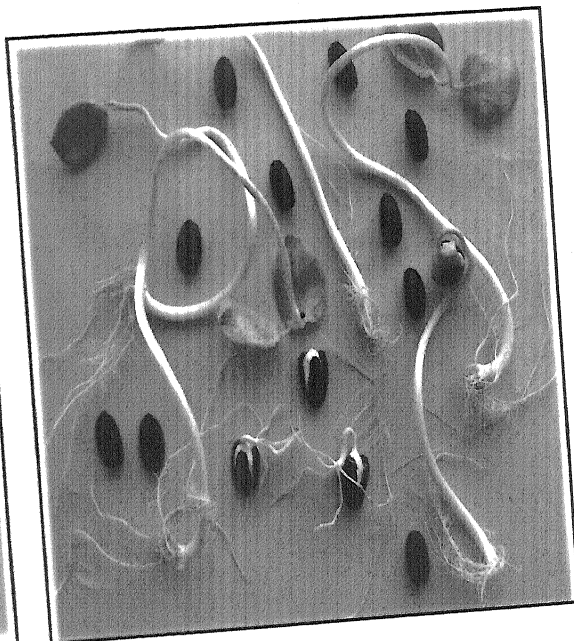


Viability in Gunny bag i.e., control (12 months)

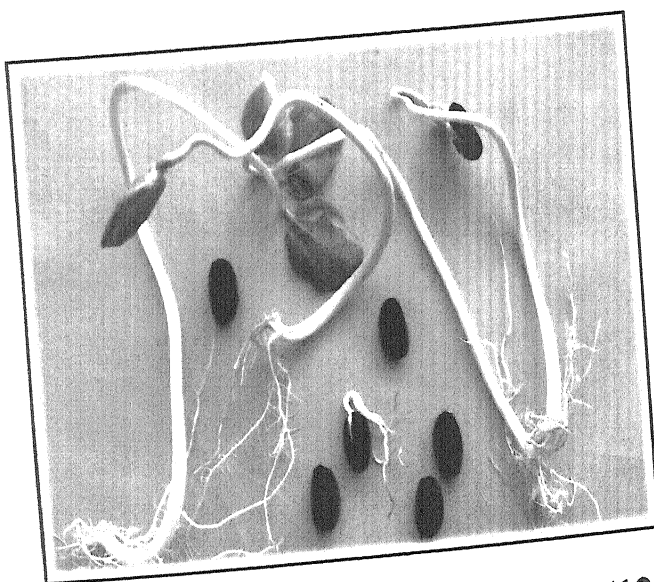
Effect of Storage containers and duration on seed germination



Germination in control

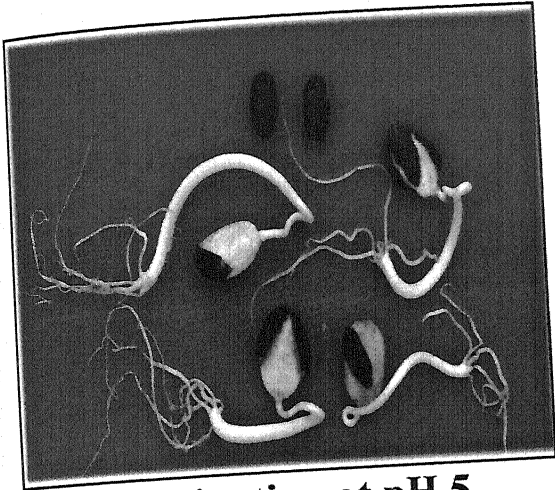


Germination in air tight plastic jar (12 months)

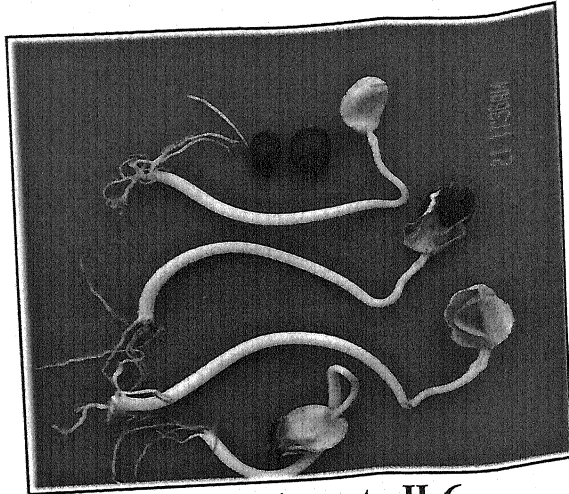


Germination in Gunny bag i.e., control (12 months)

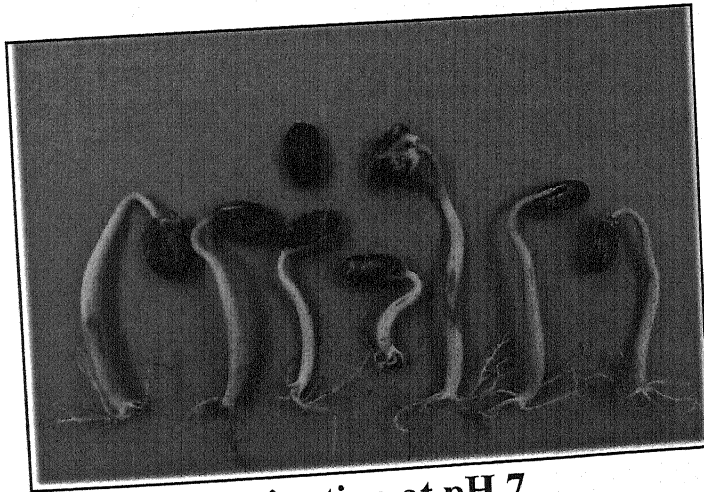
Effect of pH on Seed Germination



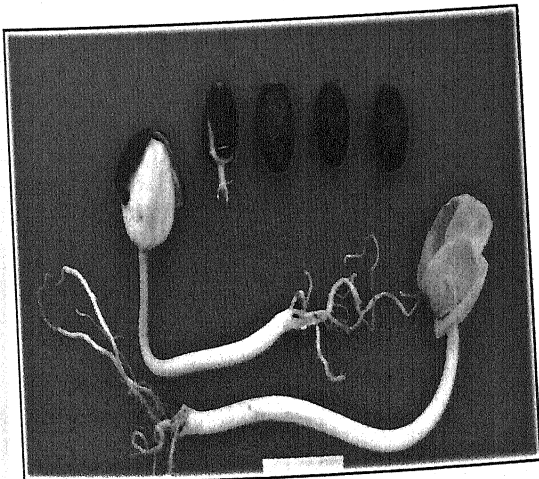
Germination at pH 5



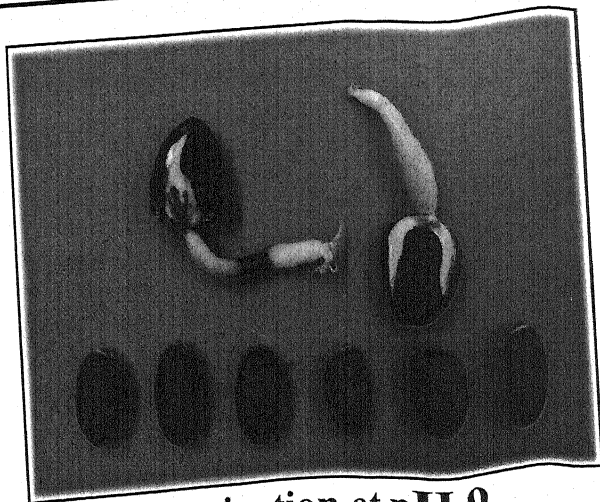
Germination at pH 6



Germination at pH 7



Germination at pH 8

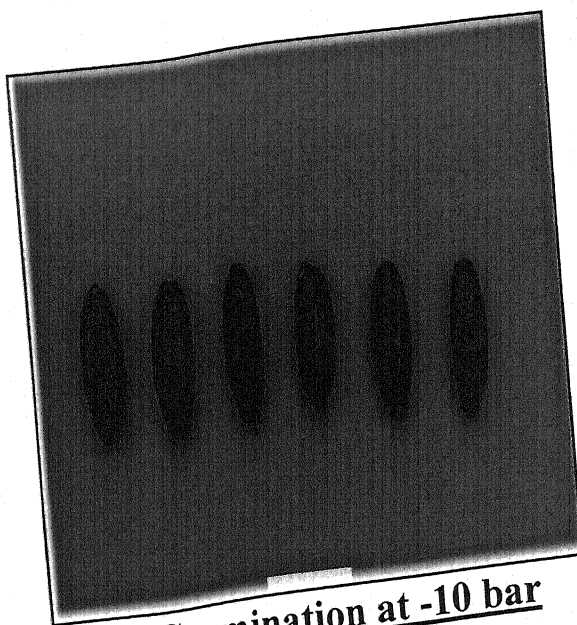


Germination at pH 9

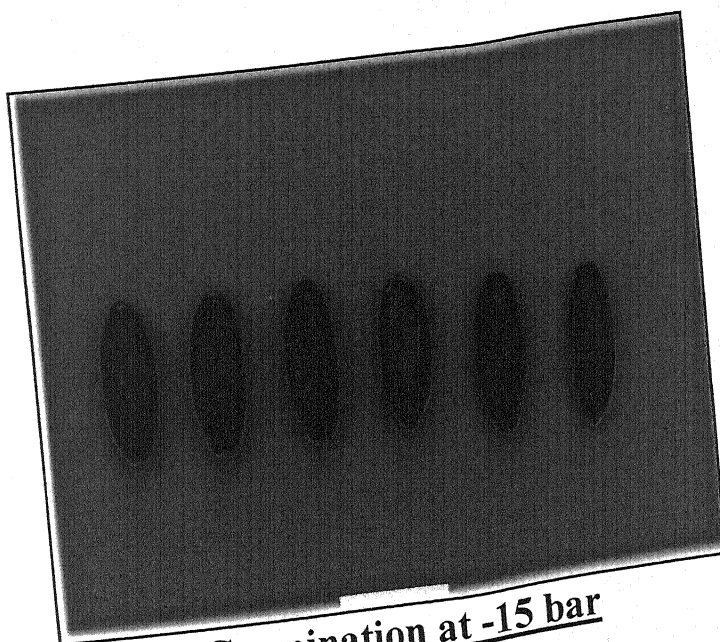
Effect of Water stress on Seed Germination



Germination at -5 bar

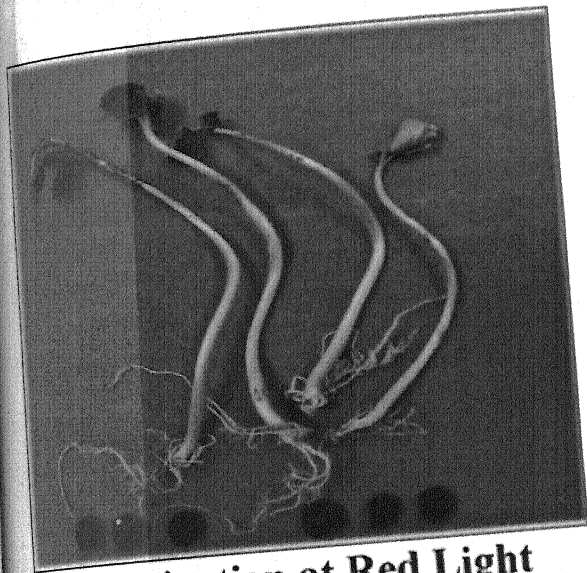


Germination at -10 bar

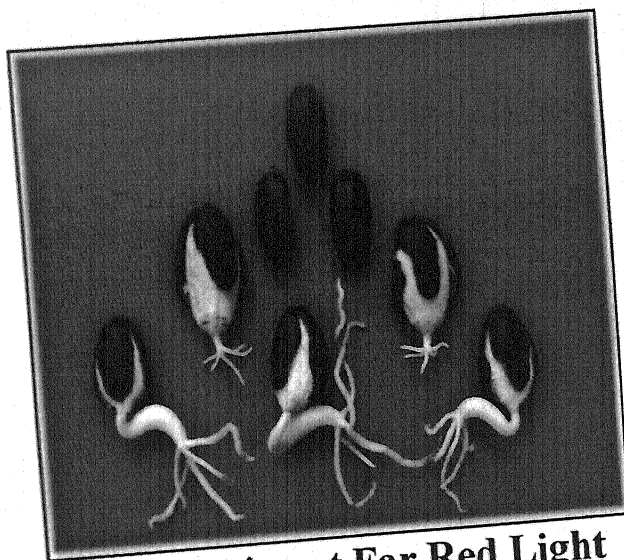


Germination at -15 bar

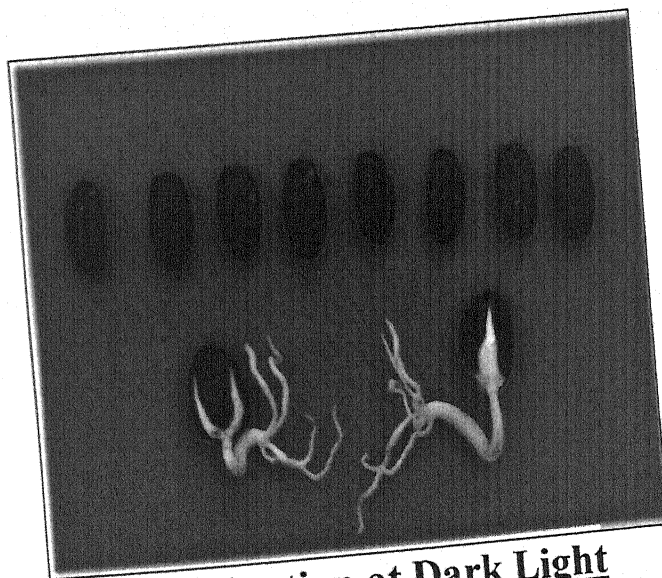
Effect of Light on Seed Germination



Germination at Red Light

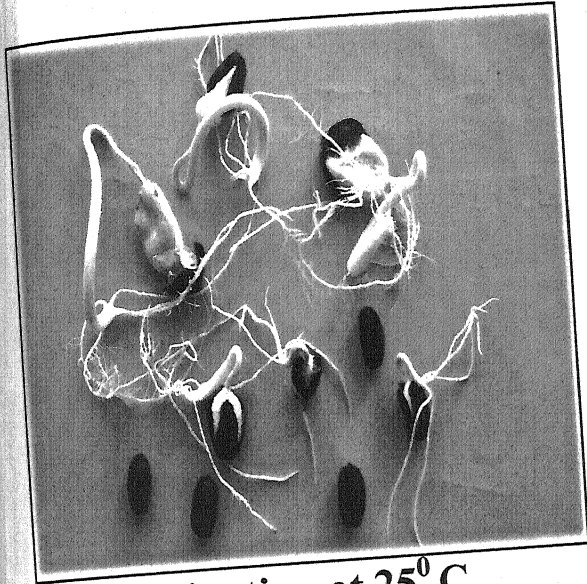


Germination at Far Red Light

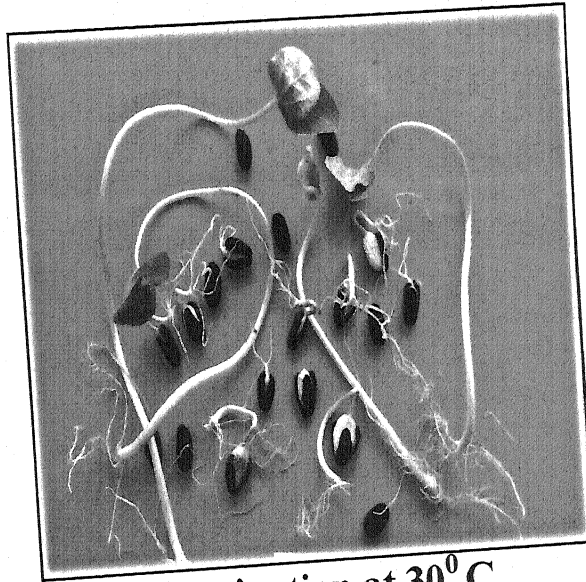


Germination at Dark Light

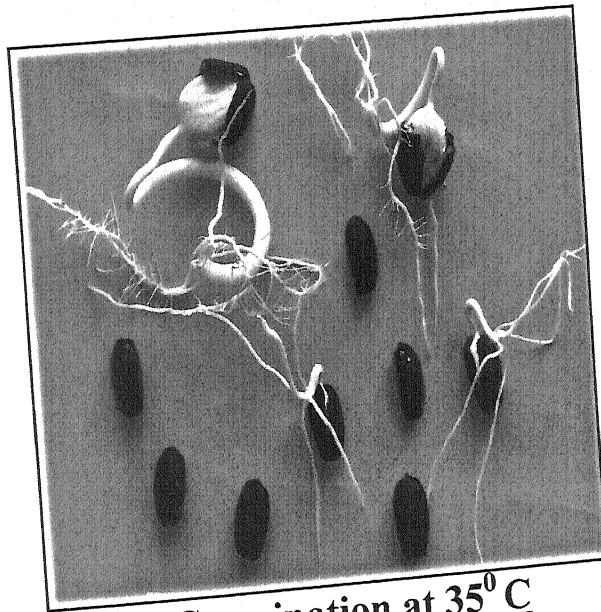
Effect of Temperature on Seed Germination



Germination at 25⁰ C



Germination at 30⁰ C



Germination at 35⁰ C

Field Photo

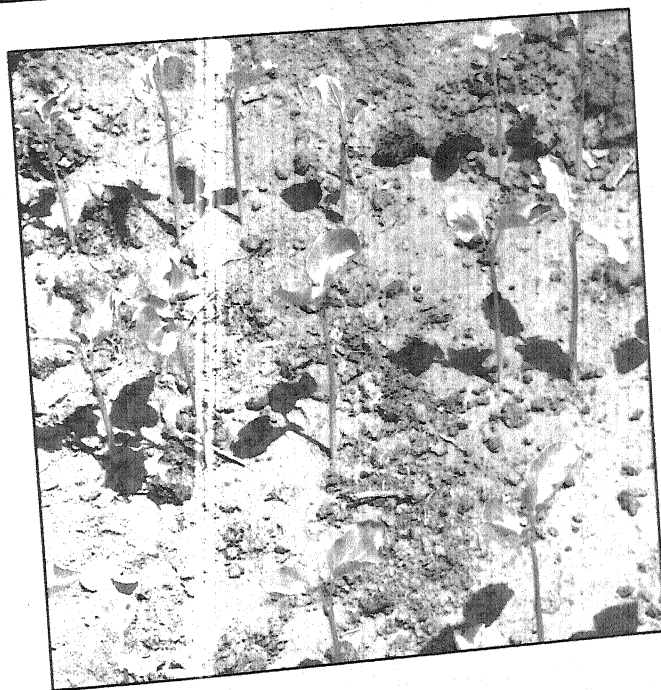
Effect of Time and Depth of sowing on seed germination
and seedling growth.



March



July



November

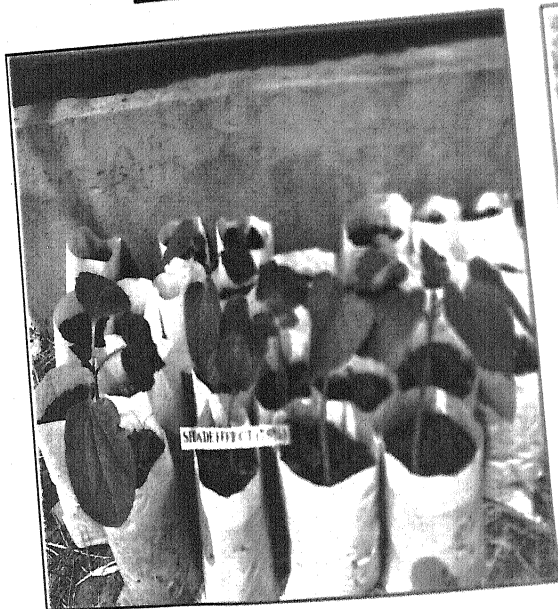
Effect of various shades on seed germination and seedling growth



50% Shade



35% Shade



75% Shade

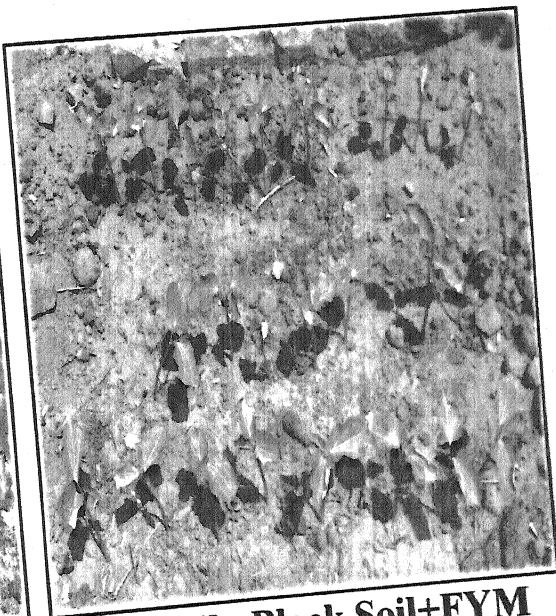


Control (No Shade)

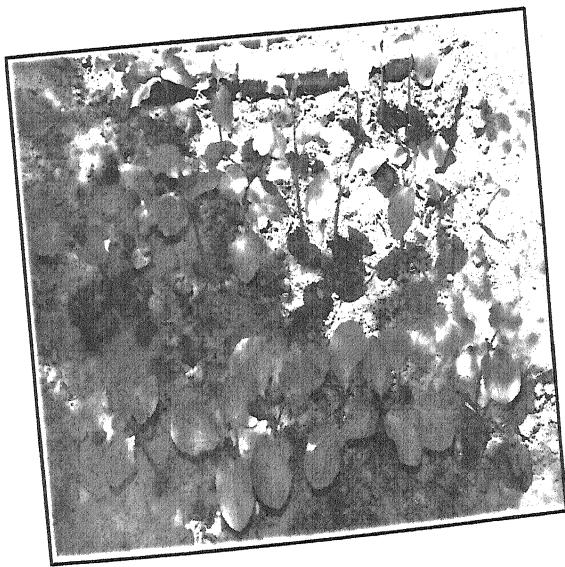
Effect of Soil mixtures in nursery bed raised seedlings



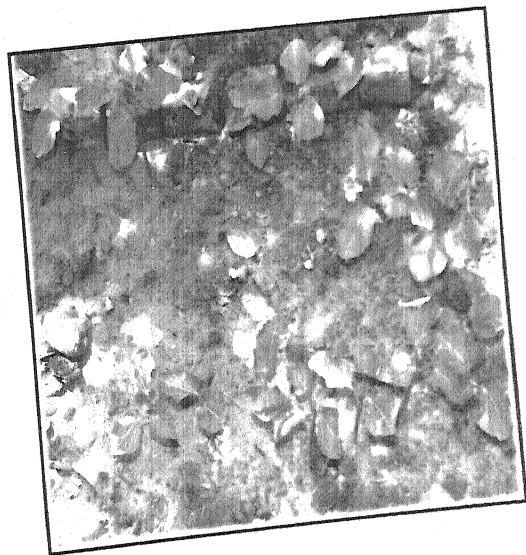
Sand + Black Soil + FYM



Red Soil+ Black Soil+FYM

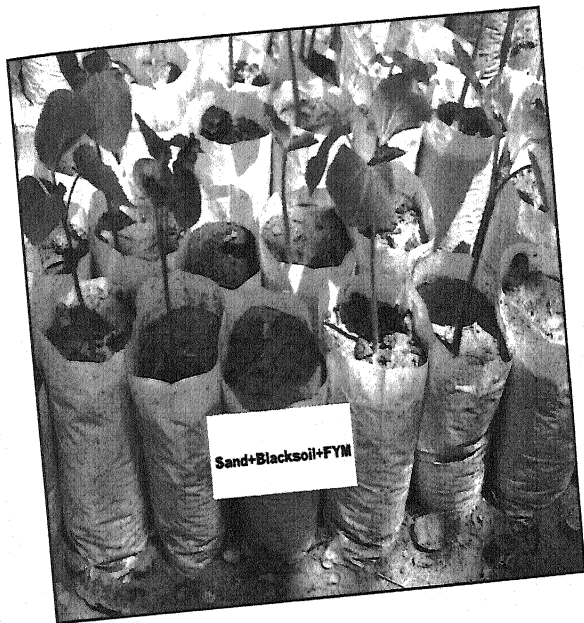


Red Soil+FYM

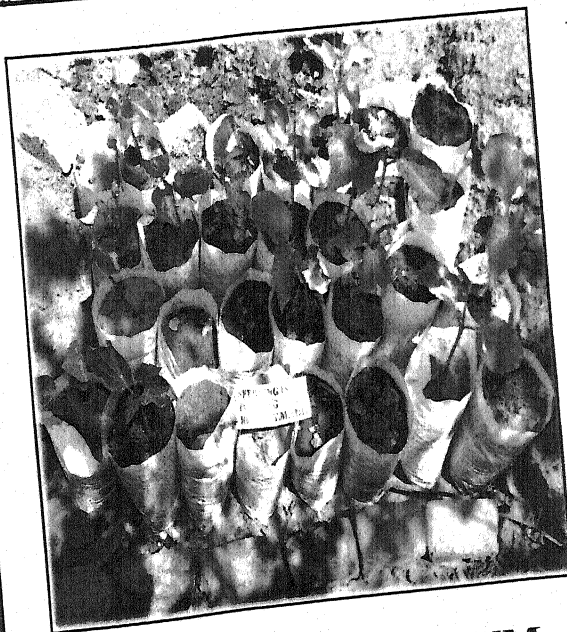


Black Soil+FYM

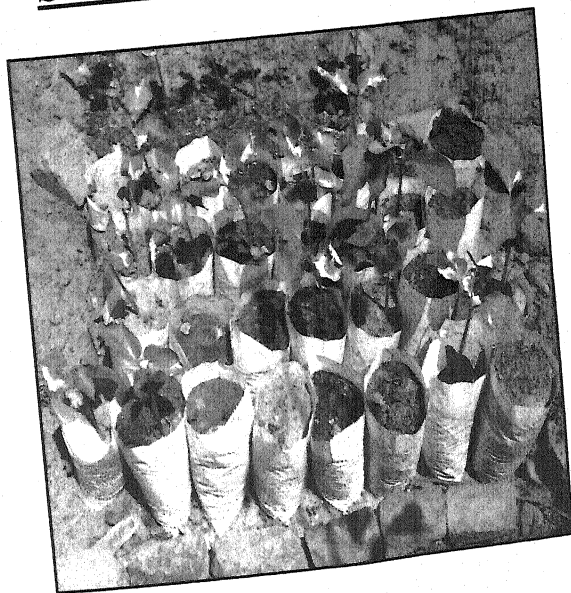
Effect of Soil mixtures in Polythene bag raised seedlings



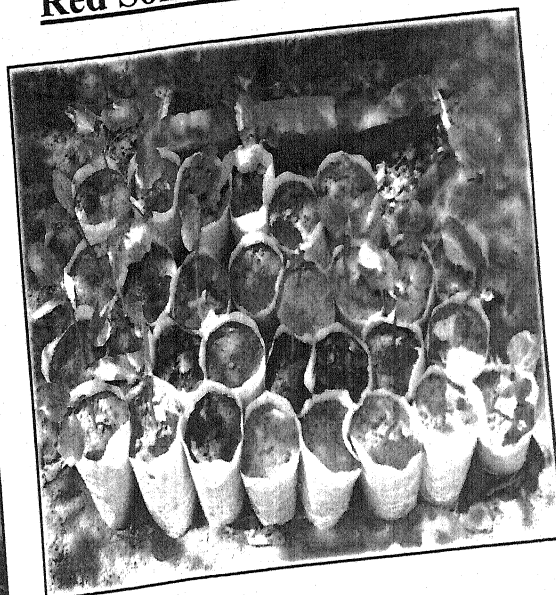
Sand + Black Soil + FYM



Red Soil+ Black Soil+FYM



Red Soil+FYM



Black Soil+FYM

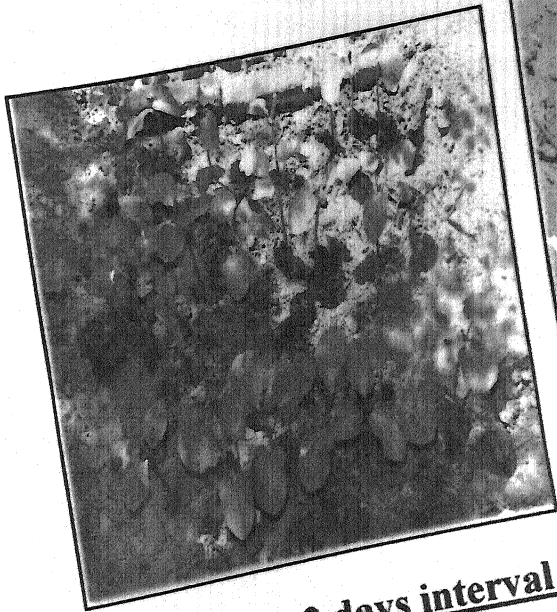
Effect of Water stress on seedling growth



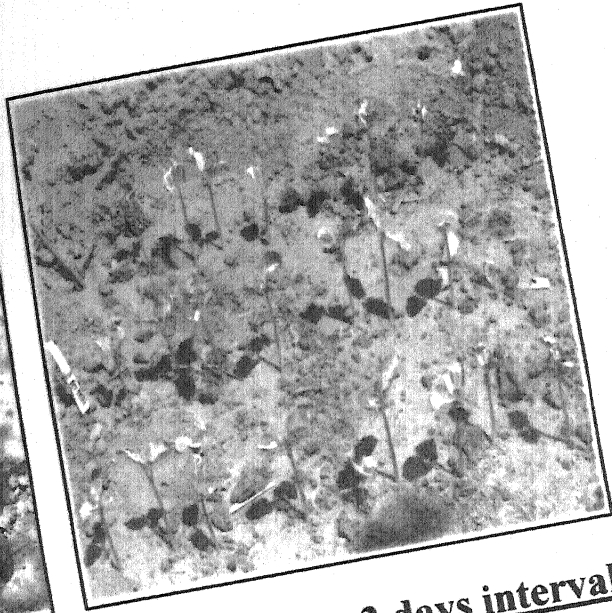
Control (daily watering)



Watering at Alternate day



Watering at 2 days interval



Watering at 3 days interval

Annexure-I
Meteorological data for the study period at NRCAF, Jhansi

YEAR- 2005

	Temp.		RH (%)		Wind veloc.	Bright Sunshine	Rainfall (mm)	No. of rainy day	Evaporation (mm/day)
	Max.	Min.	I	II					
January	21.6	6.2	90.6	45.4	3.5	6.6	2.4	0.0	2.4
February	27.5	9.9	86.0	36.8	4.0	8.8	2.8	1.0	3.9
March	33.1	15.1	76.5	31.3	5.0	9.1	37.2	2.0	5.3
April	38.3	17.5	58.2	24.6	6.3	9.5	8.2	1.0	8.6
May	43.1	24.0	47.3	28.5	7.4	9.8	0.0	0.0	11.9
June	41.7	26.9	60.0	37.8	8.5	6.0	14.2	2.0	12.0
July	32.6	25.2	90.6	68.2	7.5	4.5	214.6	14.0	5.4
August	33.7	24.2	86.8	59.5	6.7	6.8	82.8	4.0	5.4
September	33.3	24.0	90.8	64.5	5.7	7.1	75.5	7.0	4.4
October	34.1	15.5	82.2	30.0	4.1	9.7	1.8	0.0	5.4
November	30.1	10.1	82.3	24.5	3.4	8.9	0.0	0.0	3.5
December	24.0	5.2	90.3	37.3	2.7	8.6	1.2	1.2	2.3

YEAR-2006

	Temp.		RH (%)		Wind veloc.	Bright Sunshine	Rainfall (mm)	No. of rainy day	Evaporation (mm/day)
	Max.	Min.	I	II					
January	24.1	6.2	90.8	39.6	3.3	9.0	0.0	0.0	2.8
February	31.6	11.7	87.3	38.5	3.4	9.7	0.0	0.0	4.2
March	31.8	14.1	84.5	43.0	4.9	9.1	24.2	2.0	5.1
April	40.0	19.8	62.4	25.2	5.6	9.0	0.8	0.0	9.0
May	41.8	25.6	61.8	34.8	7.5	7.6	52.2	4.0	10.5
June	39.1	26.8	68.0	38.5	8.3	8.0	53.7	4.0	10.1
July	32.9	25.7	81.6	67.2	8.8	3.7	138.6	9.0	6.5
August	32.0	24.4	89.5	67.3	7.6	4.5	91.3	8.0	5.7
September	34.8	22.9	86.5	50.5	4.2	9.0	7.6	2.0	5.6
October	3.8	18.0	77.8	35.4	3.4	9.2	0.0	0.0	5.1
November	29.9	11.9	85.3	33.5	2.4	8.7	0.0	0.0	3.4
December	25.6	8.5	84.0	39.3	2.5	26.8	4.8	1.0	2.6

YEAR-2007

	Temp.		RH (%)		Wind veloc.	Bright Sunshine	Rainfall (mm)	No. of rainy day	Evaporation (mm/day)
	Max.	Min.	I	II					
January	24.1	6.1	87	42	2.5	8.7	1.8	0.0	2.7
February	26.3	10.2	88	44	4.0	8.0	39.2	4.0	3.2
March	32.4	13.1	79	28	4.4	10.1	0.0	0.0	5.7
April	40.2	20.7	55	23	5.9	10.1	2.0	0.0	9.7
May	41.7	25.6	53	27	7.7	9.6	15.1	2.0	11.5
June	39.1	27.3	67	45	10.1	8.3	143.3	5.0	10.9
July	33.7	25.4	87	64	7.9	5.1	140.3	13	5.6
August	33.0	24.9	90	66	6.0	5.8	85.8	9.0	4.3
September	34.1	23.4	90	58	3.3	8.0	119.8	6.0	4.5
October	35.0	13.8	78	26	2.8	8.7	0.0	0.0	5.0
November	30.2	10.0	88	29	1.8	7.0	0.0	0.0	3.1
December	24.0	6.0	88	40	2.3	6.1	9.6	1.0	2.3